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(2)

HANDBOOK

on

CAPABILITIES

of

ATOMIC WEAPONS

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OF

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THE ARMED FORCES SPECIAL WEAPONS PROJECT

WASHINGTON, D. C.

STATEMENT #3 CLASSIFIED

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FOREWORD

The purpose of this handbook is to set forth, in a concise and simple manner, criteria for estimating the effects of atomic weapons for use by the Services. It is designed to serve as a handy reference to aid Field Commanders and their staffs in determining the capabilities and effects of atomic weapons in respect to specific targets.

The scope of this handbook includes thermal and nuclear radiation and blast effects of atomic weapons on items of military interest such as structures, materiel and personnel. These effects are analyzed with respect to Air, Surface, Underground, and Underwater Bursts. Sufficient information is presented to allow Field Commanders to determine the best type of Weapon and Burst to be employed to obtain maximum desired effects on various types of targets.

Part I of this handbook deals with physical effects, and Part II with criteria.

The material and estimates presented in this handbook were compiled by the Weapons Effects Division of the AFSWP, and are based on the best information available to-date. As research progresses and more full scale tests are conducted, knowledge of effects of atomic weapons will increase and the handbook will be revised. In the meantime, however, this handbook can be used for arriving at a reasonable estimate of the effects of atomic weapons.

The information presented herein, pertaining to the air burst, is

based on a considerable amount of data from atomic explosions and research, both theoretical and experimental. The data presented on the Underwater Burst is based on one atomic explosion and some theoretical and experimental research. However, the information presented on the surface and underground bursts is based entirely on relatively small scale charges of TNT. It can be expected that the reliability of these data is proportional to the number of times they have been verified experimentally by the detonation of an atomic weapon.

PART I

PHYSICAL EFFECTS

CHAPTER I

GENERAL INTRODUCTION

1.1 Explosion of an atomic fission bomb.

An explosion is, for practical purposes, a sudden liberation of energy in a relatively small space. The fission of 2.2 pounds of Uranium or Plutonium will result in the conversion of only one gram (.035 ounces) of matter into energy. This sudden conversion of one gram of matter into energy is equivalent to the energy released by the explosion of 20,000 tons of TNT. In the detonation of an A-Bomb, approximately 90% of the energy is released immediately and 10% released later by the radioactive decay of the fission fragments. The energy distribution depends on the type of burst (Air, Surface, Underground, or Underwater Burst).

1.2 Nominal Bomb.

A nominal fission bomb is defined as a bomb whose energy release is equivalent to that of 20,000 tons of TNT. This is commonly referred to as a 20 KT bomb, or a bomb whose yield is 20 KT. Since this bomb is approximately equal to those used at Hiroshima, Nagasaki, and the Bikini tests, the effects of bombs of other yields have been scaled from data available from these bursts wherever possible. Furthermore, all of the physical effects described herein refer to the explosion of a single bomb. It has been predicted that if two fission bombs were burst in the same vicinity within a short time (1-10 minutes), various

losses in yield are possible depending on the type of weapon, and the time and distance between detonations.

1.3 Types of Bursts.

The position at which a bomb is burst, with respect to the earth's surface, determines in a great measure the relative magnitudes of the various physical effects. It is possible to distinguish four types of bursts as indicated above. For purposes of this handbook these are defined as:

a. Air Burst : height of burst, 500 feet or greater,

b. Surface Burst : height of burst, 50 feet or less,

c. Underground Burst : depth of burst, 50 feet or greater,

d. Underwater Burst : depth of burst, 50 feet or greater.

These limits are established for the purposes of presentation. It can be expected that weapons burst in between the limits set above will exhibit characteristics of both limiting conditions. Further, the above limits apply to a nominal bomb. To be precise, for bombs of other yields, limiting heights and depths should be scaled in accordance with the cube root law presented hereafter.

CHAPTER II

THE AIR BURST

2.1 Brief Description of an Air Burst.

2.11 The detonation of a 20 KT bomb is first observed as a flash of light which becomes an expanding fireball.. When the fireball has grown to 45 feet in diameter, it exists as a ball of hot gases at approximately 300,000 degrees centigrade and at hundreds of thousands of pounds per square inch overpressure (pressure in excess of atmospheric). The fireball expands rapidly to a maximum radius of 450 feet. During this expansion a "skin" of compressed air called the shock front, is formed on the surface of the fireball. The shock front detaches itself from the fireball during its expansion and proceeds outward radially at very great speed, gradually slowing to the velocity of sound as the pressure in the front diminishes.

2.12 A short time after the shock front has detached itself from the fireball a negative pressure (below atmospheric) is formed behind the shock front. Under certain atmospheric conditions (high relative humidity) what is known as a Wilson cloud appears. This cloud is caused by the condensation of water vapor in the atmosphere due to the drop in temperature that accompanies the negative pressure phase. It has been estimated that the relative humidity must be 60% or greater for the formation of the Wilson cloud.

2.13 Because of its high temperature and low density, the ball of

fire rises. As it rises it cools, allowing the vaporized particles of the bomb and its casing and other constituents of the gas bubble to condense, thus forming water droplets and solid particles. This highly radioactive smoke is carried into the upper atmosphere where it is diluted and scattered by the winds.

2.2 Energy Distribution.

The partition of energy for an air burst is as follows:

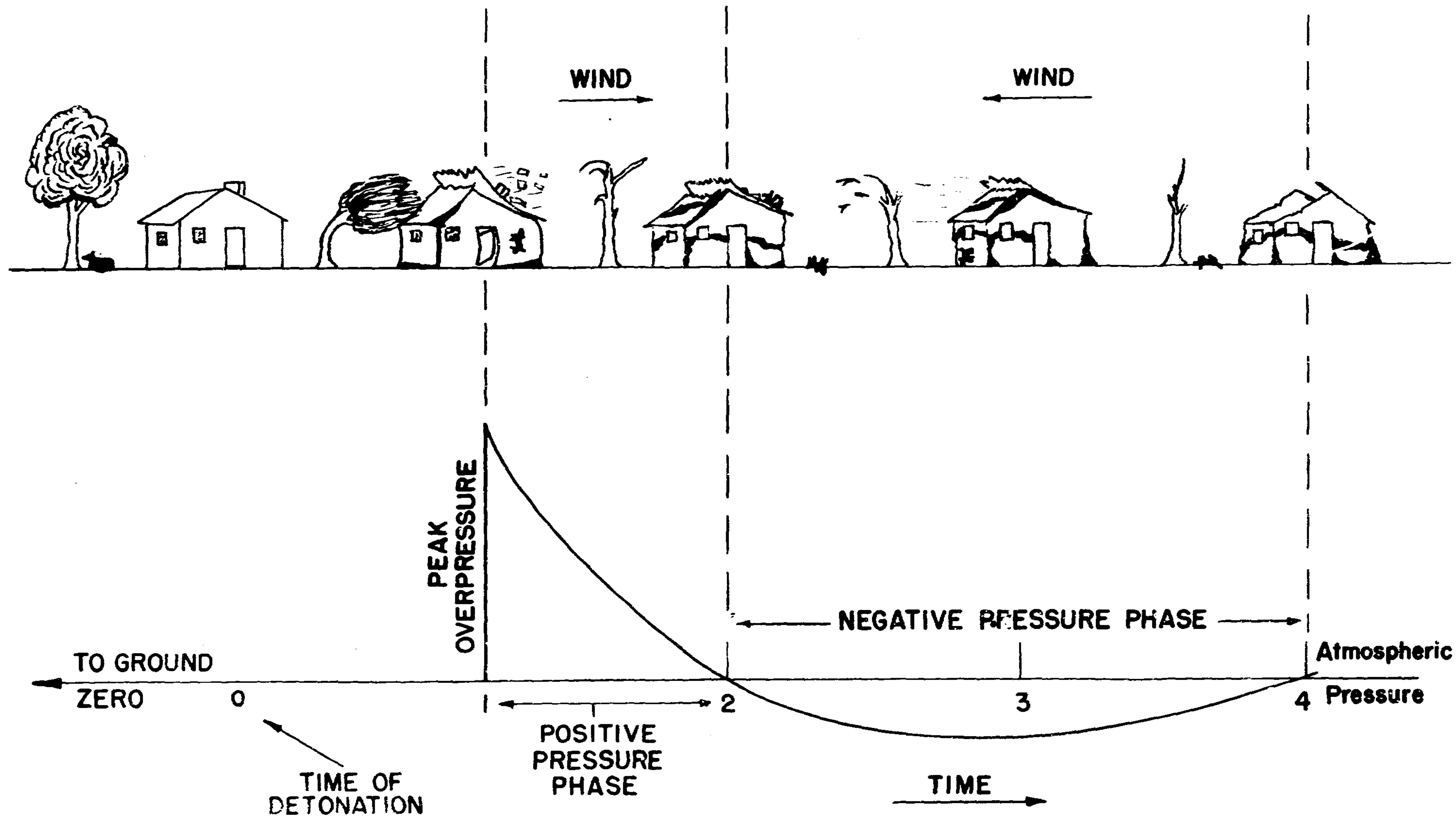
Air Blast		55%
Thermal Radiation		30%
Nuclear Radiation		15%
Instantaneous Gammas and Neutrons	5%	
Residual Contamination	10%	

It should be noted that the partition of energy is not a direct measure of the relative magnitude of the effects of blast and thermal and ionizing radiation.

2.3 Blast Effects.

2.31 The Shock Wave :

As explained above, the expansion of the hot gases produced by the explosion causes the formation of a shock wave. The shock wave is characterized by an instantaneous rise in pressure called the shock front, after which the pressure decreases to atmospheric in approximately 0.5-1.0 seconds. This is called the positive pressure phase. The pressure continues to fall gradually to a minimum and returns to atmospheric in 2.5-5.5 seconds. This phase is known as the negative pressure phase. The decrease in pressure in the negative phase is always small compared



NOTE: GROUND [illegible] POINT ON GROUND DIRECTLY UNDER AIR BURST

REPRESENTATION OF BEHAVIOR ACCOMPANYING
A SHOCK WAVE STRIKING A BUILDING

FIG. 2.31

to the increase in pressure in the positive phase. During the positive pressure phase there is an associated wind moving in the same direction as the shock front. This wind decays to zero velocity and reverses its direction during the negative pressure phase. This phenomena is shown graphically in Figure 2.31.

2.32 Peak Overpressure vs. Distance, Scaling.

a. In the atmosphere, in the absence of reflecting surfaces, (Free Air), the peak pressure decreases rapidly as the shock front is propagated. The distance from an explosion at which a given peak overpressure will be experienced in free air has been found to be proportional to the cube root of the energy yield of the bomb. This scaling is shown in equation (2.1) below:

$$\frac{d_1}{d_2} = \left(\frac{W_1}{W_2}\right)^{1/3} \quad \text{: at same peak overpressure} \qquad (2.1)$$

where:

W is bomb yield

d is the distance from the bomb.

Example:

Given: 20 KT bomb produces an overpressure of 7 pounds per square inch (psi) at a distance of 3,500 feet.

Find: Distance at which a 100 KT bomb produces the same overpressure (7 psi).

Solution: $W_1 = 20\,KT$, $W_2 = 100\,KT$, $d_1 = 3500$

$$\therefore \frac{3500}{d_2} = \left(\frac{20}{100}\right)^{1/3}$$

$$d_2 = 3500\,(5)^{1/3}$$

$$(5)^{1/3} = 1.7$$

From the cube root curve in Appendix A,

$$\therefore d_2 = \underline{\underline{6000\ ft}} \quad \underline{ans}$$

Alternate Solution:

Figure 2.32a shows the overpressures vs distances for various KT yields in free air. Therefore, the answer to this problem can be obtained directly from this figure by finding the intersection of 7 psi with the 100 KT curve.

b. The duration of the positive pressure phase at any given overpressure has also been found to be proportional to the cube root of the bomb yield. This scaling is shown in equation (2.2) below:

$$\frac{t_1}{t_2} = \left(\frac{W_1}{W_2}\right)^{1/3} \quad \text{: at the same overpressure} \tag{2.2}$$

where t is the duration of the positive pressure phase.

Example:

Given: The duration of the positive pressure phase, in free air, from a 20 KT bomb at a given

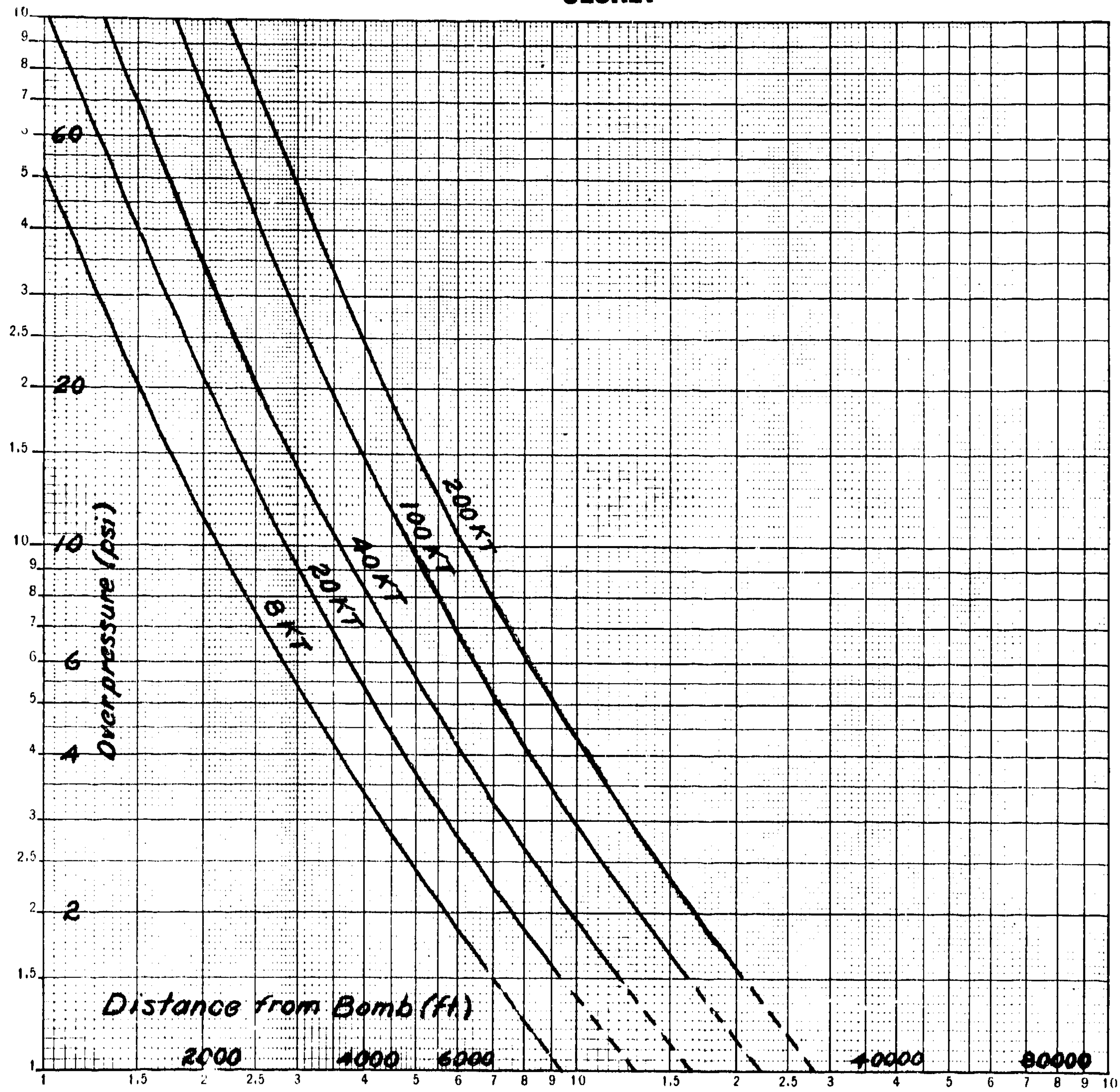


Figure 2.32a Free Air Overpressure vs. Distance for Various KT Yields

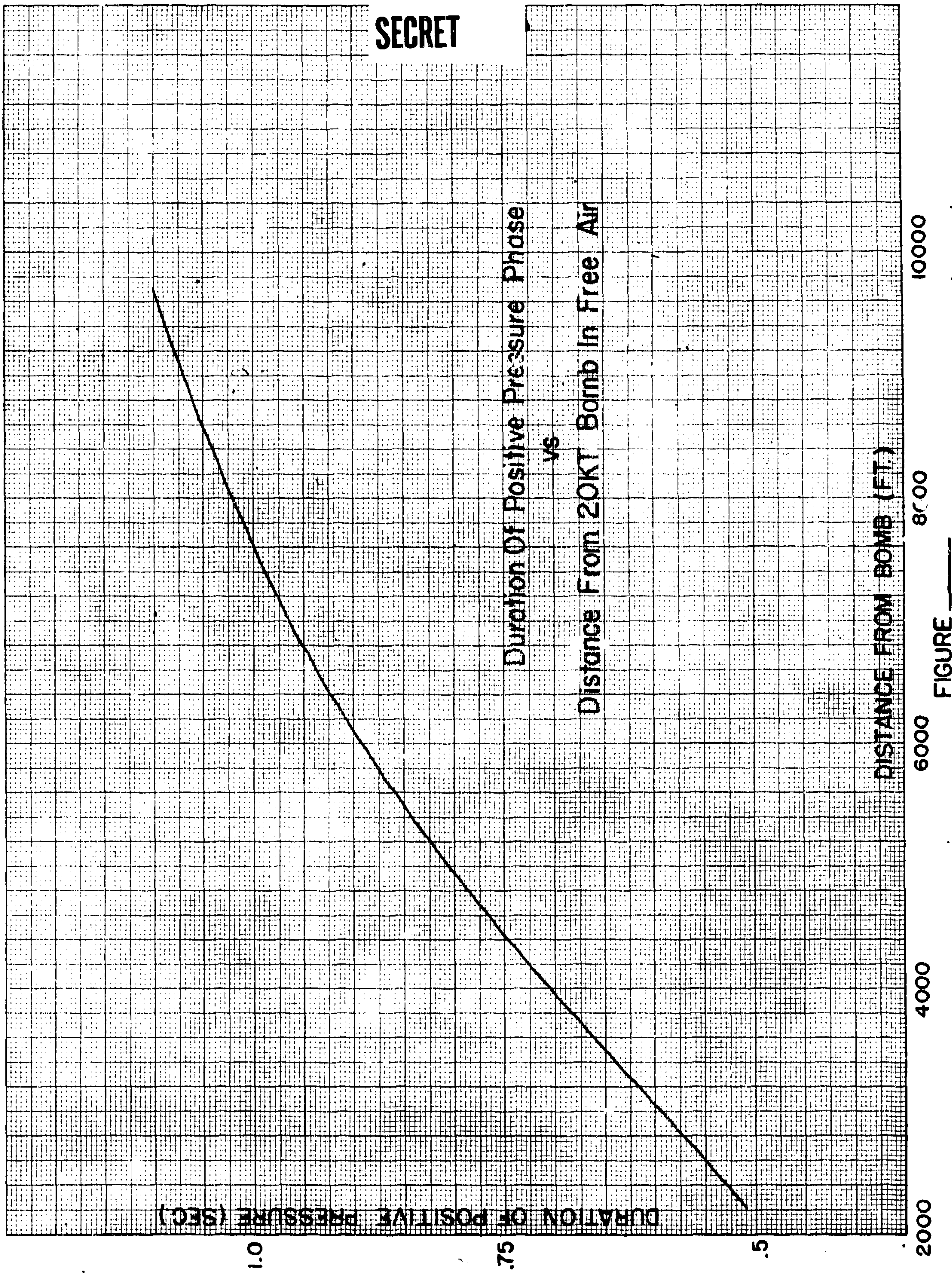

Duration Of Positive Pressure Phase
vs
Distance From 20KT Bomb In Free Air
DURATION OF POSITIVE PRESSURE (SEC)
1.0
.75
.5
DISTANCE FROM BOMB (FT.)
2000
4000
6000
8000
10000
FIGURE ___

Figure 2.32b

overpressure is 0.7 seconds, at 4,000 feet from the bomb. See Figure 2.32b.

Find: 1- The duration of the positive pressure phase, at the same overpressure, from a 160 KT bomb.

2- The range at which this duration is experienced.

Solution:

1- $$\frac{0.7}{t_2} = \left(\frac{20}{160}\right)^{1/3} ; \quad t_2 = 0.7\,(8)^{1/3}$$

$$\therefore \; t_2 = \underline{\underline{1.4 \text{ sec}}} \qquad \underline{\text{ans}}$$

2- $$\frac{d_2}{4000} = \left(\frac{160}{20}\right)^{1/3} ; \quad d_2 = 4000\,(8)^{1/3}$$

$$\therefore \; d_2 = \underline{\underline{8000 \text{ ft}}} \qquad \underline{\text{ans}}$$

c. Figure 2.32c shows the time of arrival of the shock wave vs distance for a 20 KT bomb in a homogeneous atmosphere with no wind. The difference in time of arrival, at ranges beyond 2,000 feet, for yields between 1 KT to 200 KT is insignificant.

2.33 Mach Front :

The stronger the shock wave and the hotter the medium, the faster the shock wave will travel. Moreover, it heats the air through which it travels. When the shock wave in the air strikes a much denser medium, such as the earth's surface, it is reflected with a resulting increase in pressure. Since the reflected wave is stronger and since it travels through air preheated by the incident wave, it will travel faster than the incident wave. At some angle of incidence, depending on the strength of the shock (45° for an overpressure of 15 psi in the

incident shock front) a Mach front will be formed. This front is caused by the reflected wave, which is traveling faster, riding up on the incident wave to form a common reinforced front. The Mach front extends from the point of intersection of the incident and reflected waves to the plane surface below. The point of intersection of the incident front, the reflected front, and the Mach front is called the triple point. As the shock is propagated along the plane surface, the triple point rises because of the difference in the velocities of the incident and reflected waves, previously explained. Figure No. 2.33 shows the incident wave, the reflected wave, the merger of these two waves into the Mach wave, (or Mach Front) and the path of the triple point.

2.34 Optimum Height of Burst :

a. Since the reflected pressure at the surface and the formation of the Mach Front are dependent upon the strength of the incident shock and the angle of incidence, the height at which the bomb is burst is critical. There is a calculated height of burst which will maximize the area over which a given peak overpressure is obtained. The bombs which were dropped at Nagasaki and Hiroshima were burst at approximately 2,000 feet, which maximized the area subjected to a peak overpressure of 20 psi. Figure No. 2.34a shows the variation in overpressure at the surface of the earth at various distances from ground zero for three different heights of burst of a nominal 20 KT bomb.

b. The peak overpressure necessary for destruction depends on the type of target that is to be destroyed. Therefore, by calculating the height of burst that will give the largest area over which a

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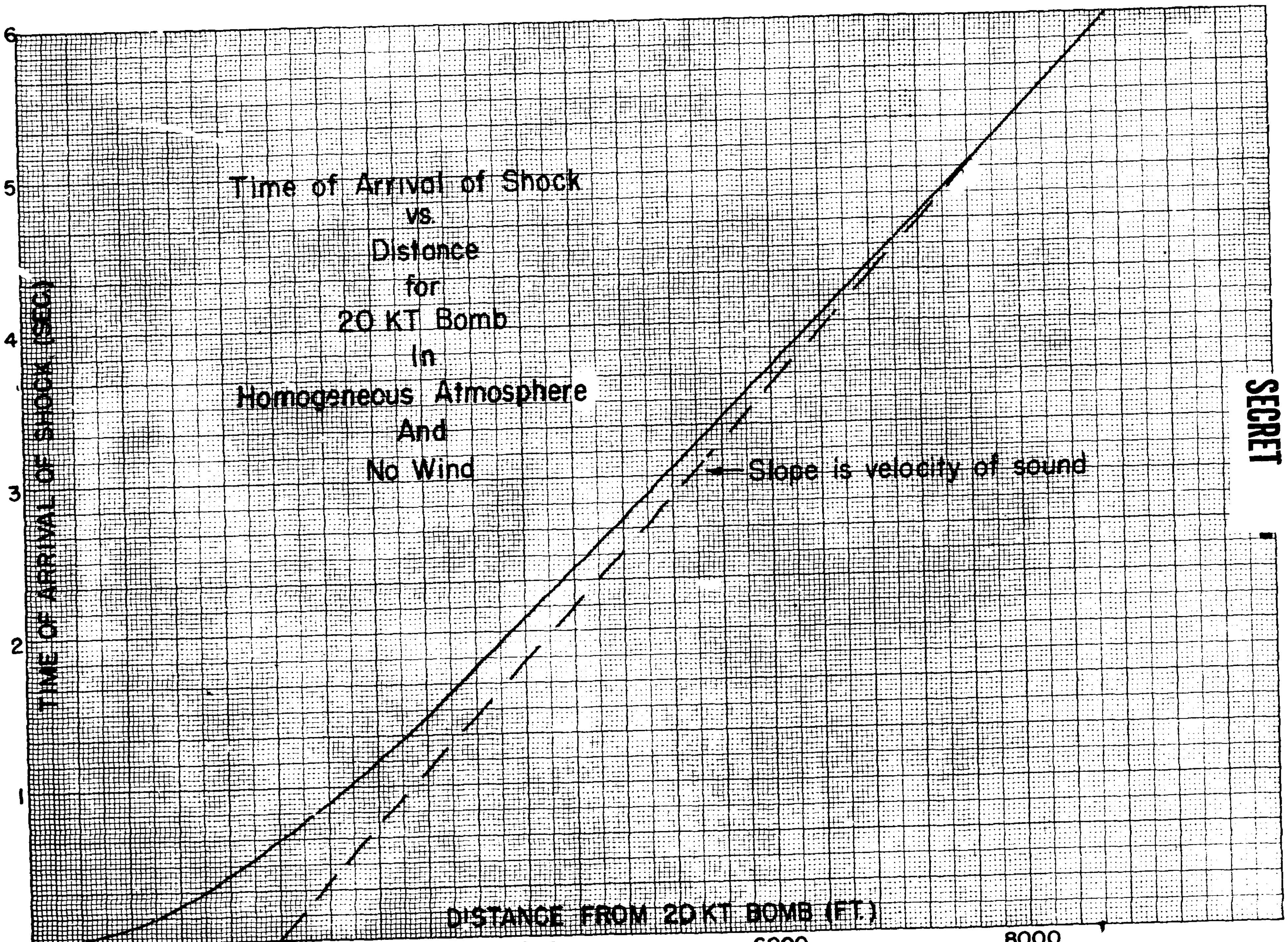

FIGURE 2.32c

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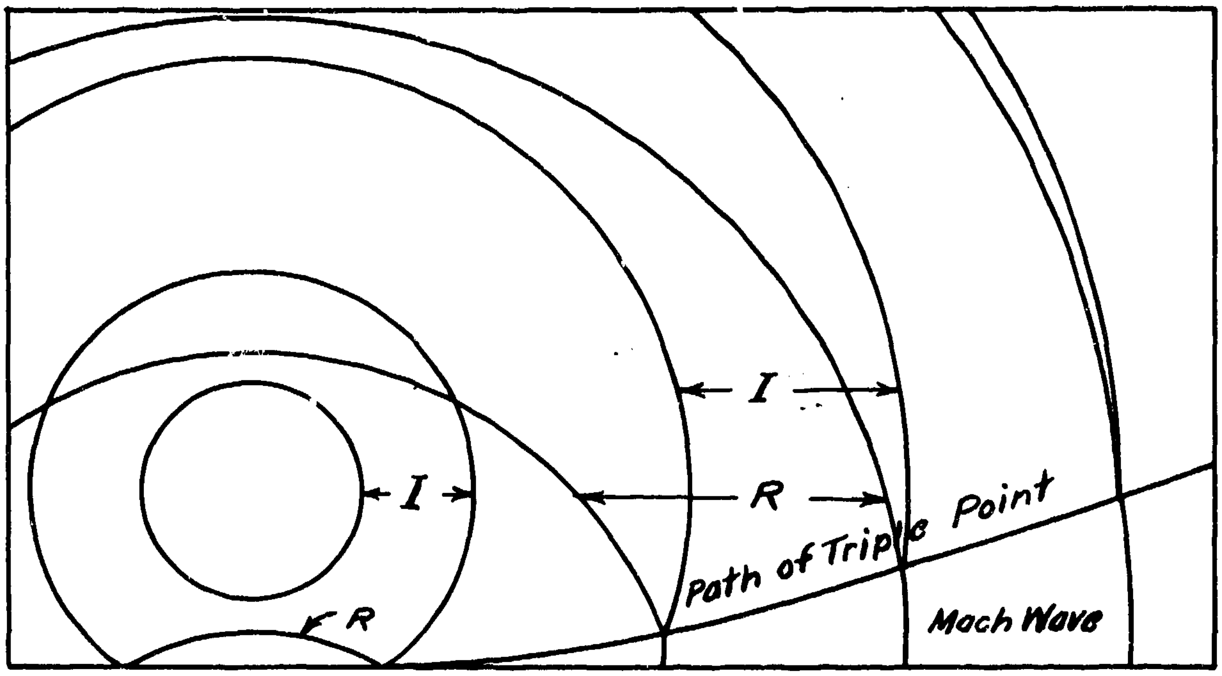

I - Incident Wave

R - Reflected Wave

Figure 2.33 Successive Stages in the Formation of the Mach Stem

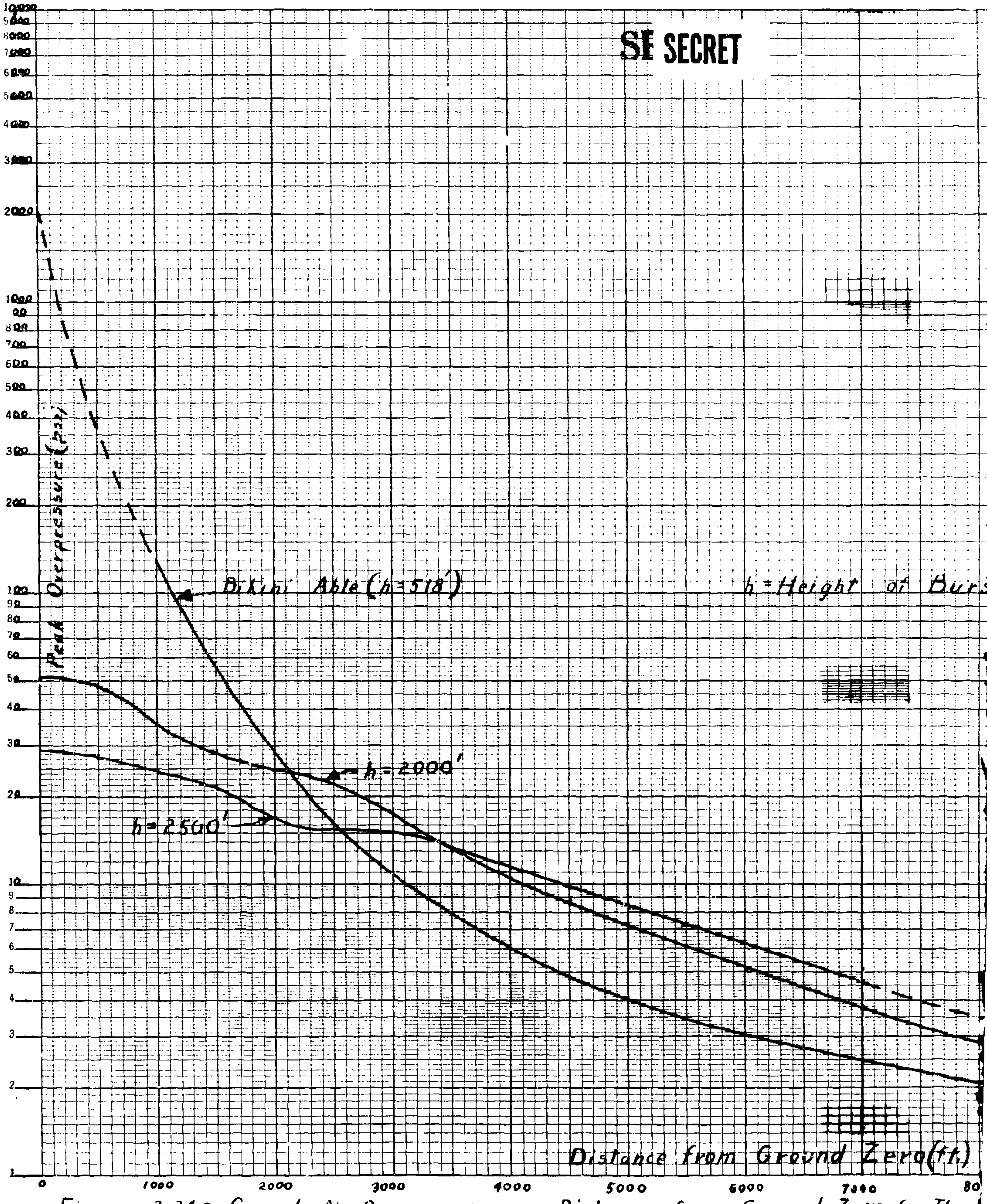

Figure 2.34a Ground Air Overpressures vs Distance from Ground Zero for Three

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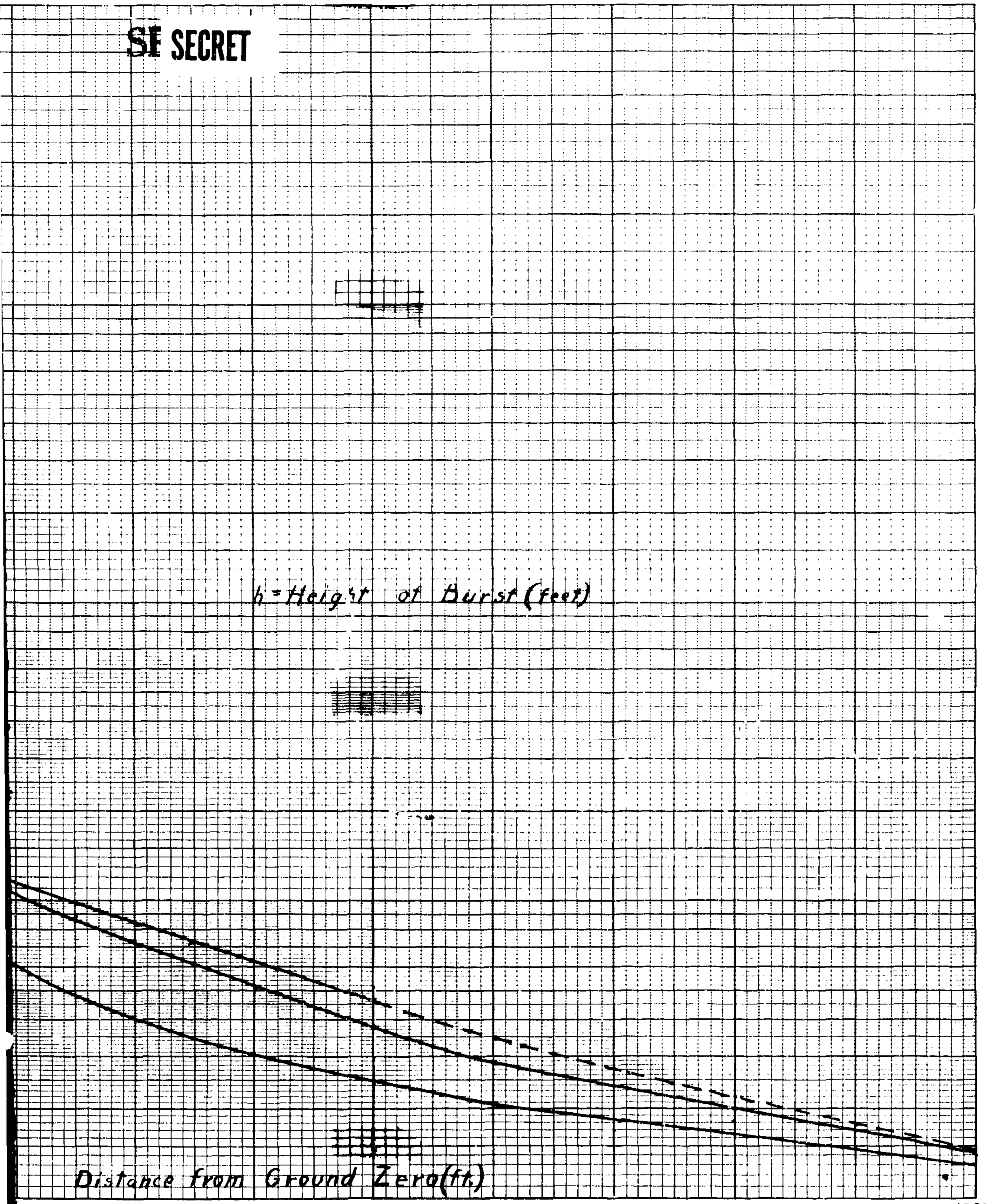

vs Distance from Ground Zero for Three Different Heights of Burst (20 Kt Bomb)

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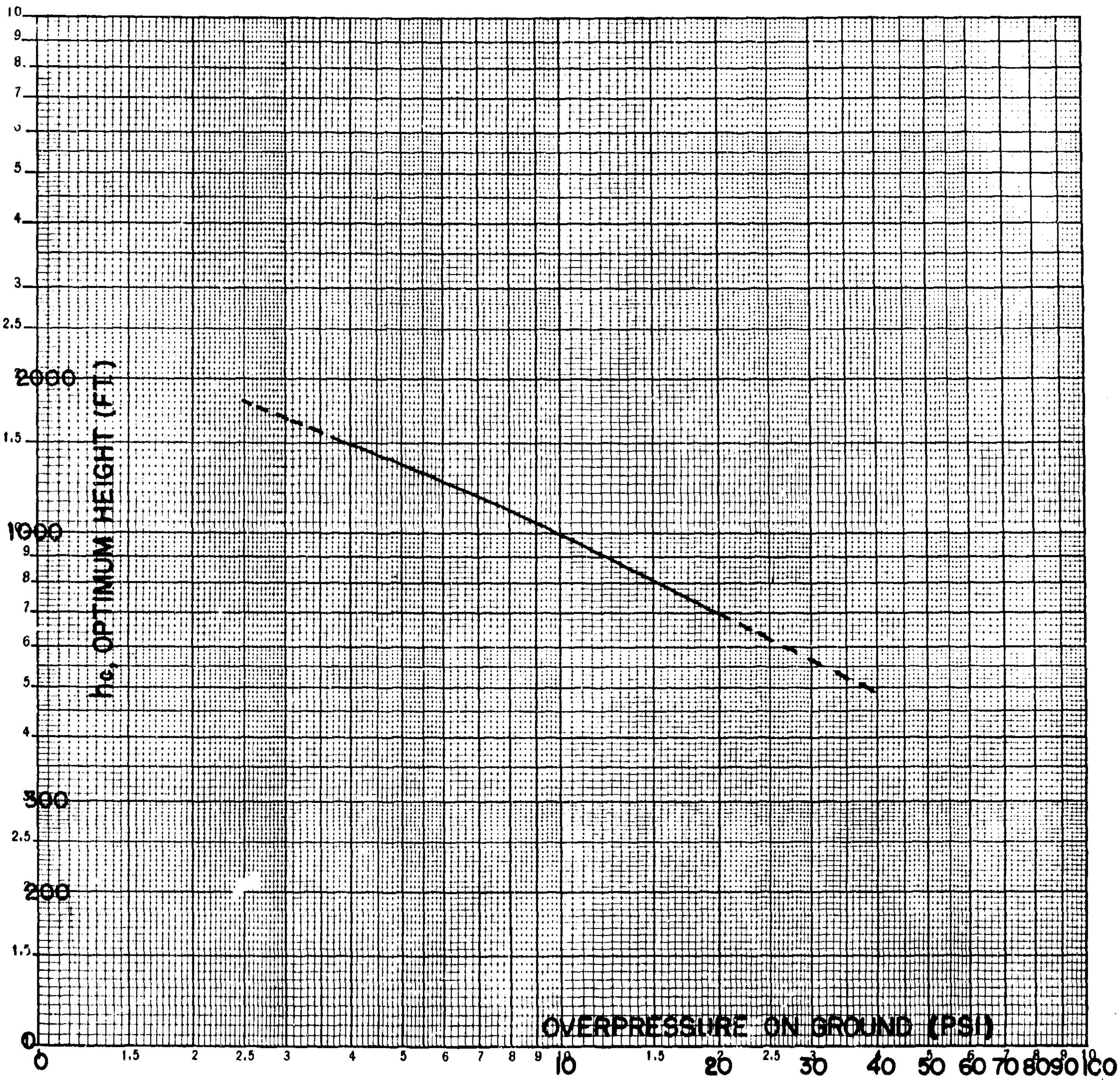

Optimum Height of Burst vs. Air Overpressure on the Ground
for
1 KT Bomb
FIGURE 2.34b

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desired peak overpressure will extend, damage to targets subjected to this selected peak overpressure, is maximized. In Figure No. 2.34b the optimum height for a 1 KT yield is plotted vs peak overpressure on the surface. To determine the optimum height of burst of a bomb (X), multiply the optimum height of burst for the 1 KT bomb by the cube root of the KT yield of bomb (X).

Example:

Given: The required overpressure for a desired damage is 10 psi.

Find: 1- Optimum height of burst for a 1 KT bomb.

2- Optimum height of burst for a 20 KT bomb.

Solution:

1- From figure 2.34b, the optimum height of burst for maximizing 10 psi for a 1 KT bomb is 1,000 feet. ans

2- $1000 \times (20)^{1/3} = 2700$ feet. ans

c. To determine the radius from ground zero to which a 10 psi overpressure will extend, refer to Figure No. 2.34c. This curve is a plot of peak overpressures on the ground vs distance from Ground Zero. In plotting this curve, it has been assumed that the optimum height of burst was used for each given peak overpressure. To use Figure No. 2.34c for bombs of other yields, multiply the maximum radius given for a 1 KT bomb by the cube root of the KT yield of bomb in question. (See, also, Figures 2.6a to 2.6d).

Example:

Given: The required peak overpressure for adesired

damage is 10 psi.

Find: 1- The maximum radius for a 1 KT bomb.

2- The maximum reaius for a 20 KT bomb.

Solution:

1- From figure 2.34c: Maximum radius for 10 psi is 1,650 feet. ans

2- $1,650\ (20)^{1/3}$ = 4500 feet. ans

d. It is important to note that a detonation at an altitude higher than the calculated optimum height for a desired psi overpressure will markedly reduce the radius or extent of the desired psi; whereas a detonation at an equal distance lower than this optimum height reduces relatively little the radius that the desired psi will extend from ground zero. This fact is clearly evident in Figure No. 2.34d which is a plot of distances from ground zero of various psi vs height of burst, for a 1 KT burst. The height of the Mach Stem (i.e., Mach Front) is also indicated on this figure.

2.35 Low Heights of Burst :

a. The curve plotted on Figure No. 2.34a for a 500 foot height of burst is based on experimental data from the air burst fired at Bikini (Bikini Able). It should be noted that for this height of burst the peak reflected overpressure at ground zero is 2,000 psi. Further, overpressures measured at ranges greater than 2,500 feet for a 500 foot height of burst are less than overpressures obtained at those ranges for a 2,000 or 2,500 foot height of burst. In the Bikini Able shot, the Mach Stem was formed somewhere between Ground Zero and 1,000 feet.

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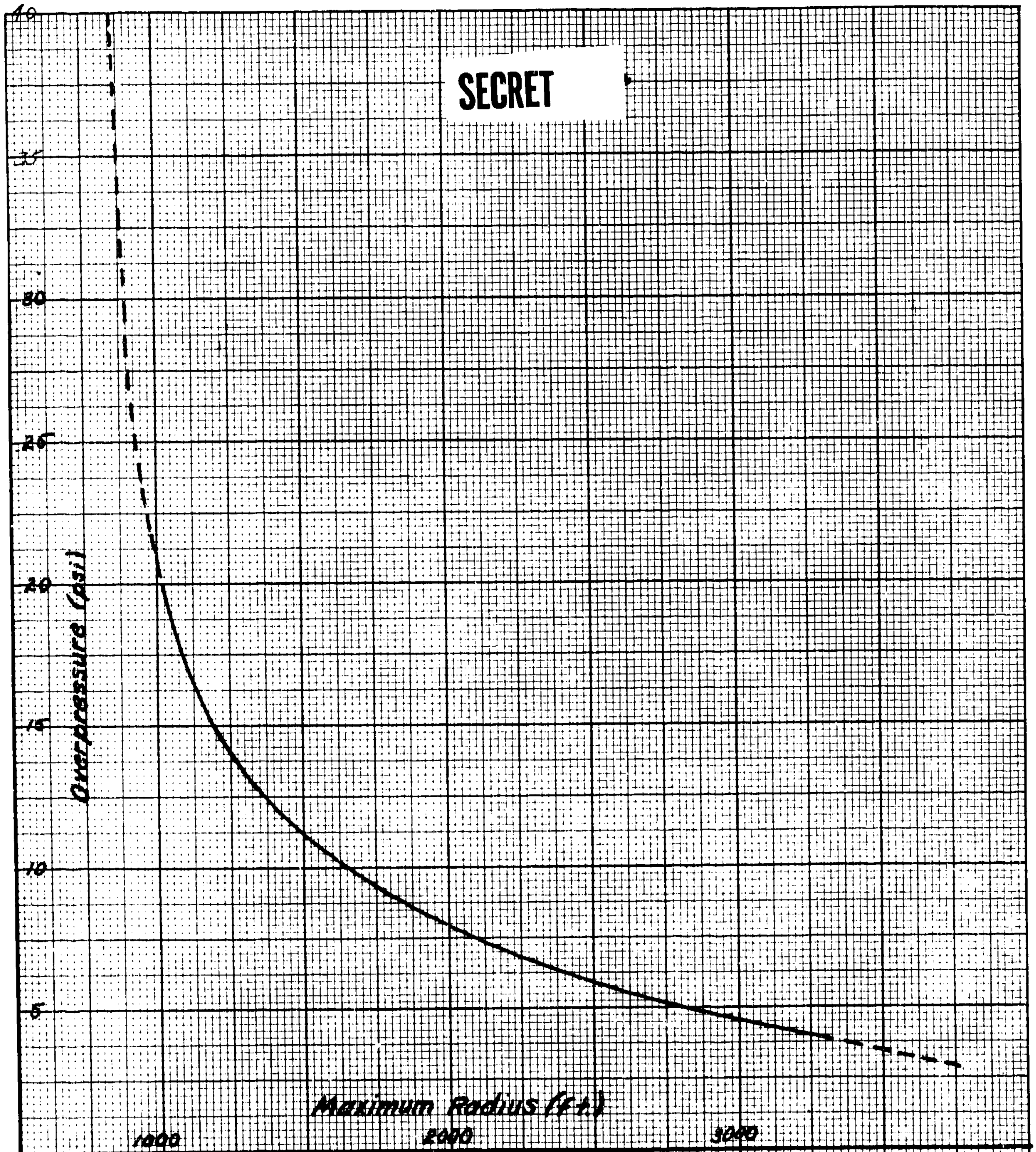

Figure 2.34C Maximum Radius vs. Overpressure in Air at Ground Surface for One KT Yield

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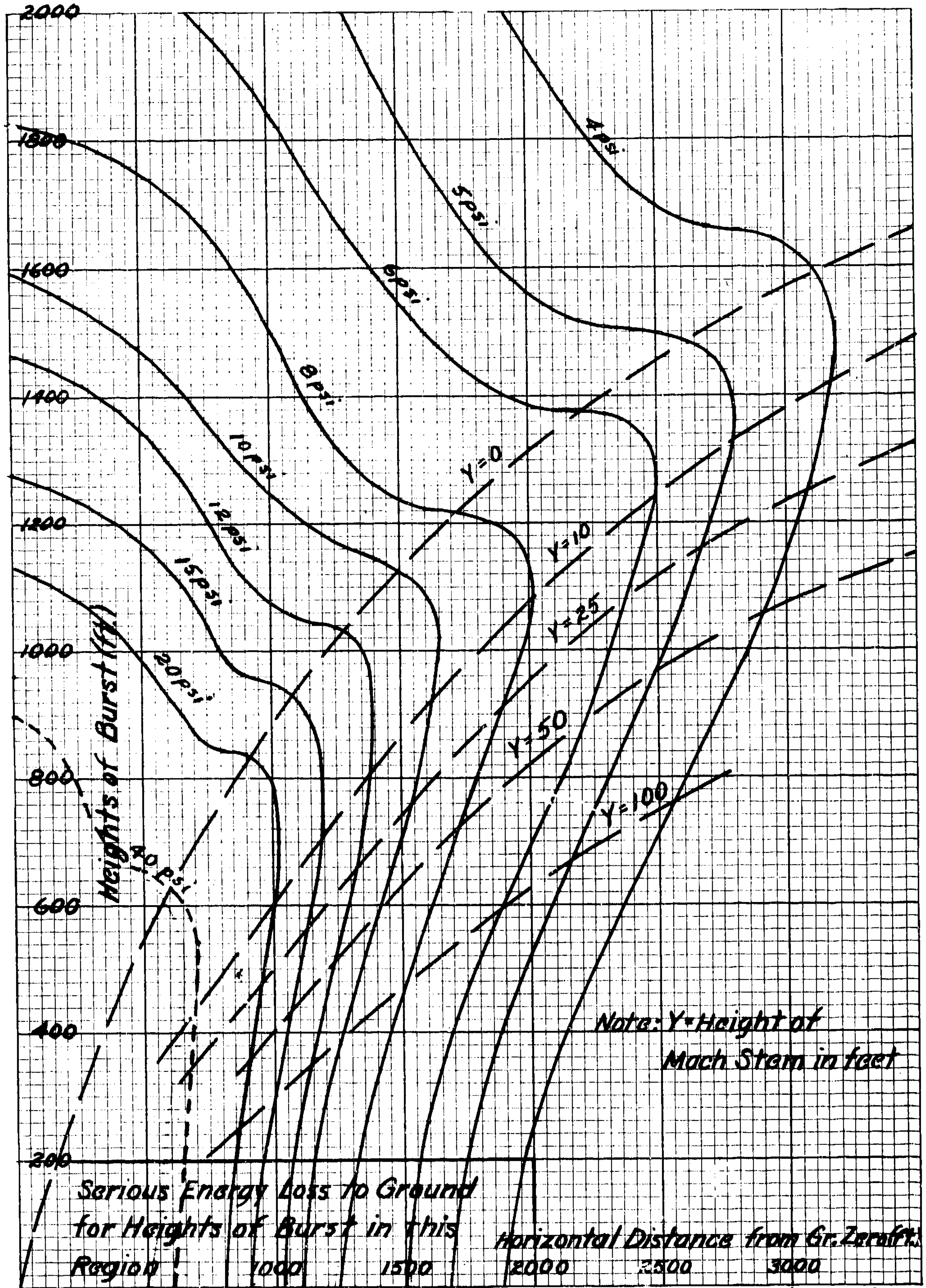

Figure 2.344 Height of Burst vs. Horizontal Distance for 1KT Bomb as Function of Peak Pressure and Height of Mach Stem

Therefore, in Figure No. 2.34a, this portion of the curve is plotted as a dotted line.

b. In general, it can be stated that peak reflected overpressures on the ground in the vicinity of ground zero will be higher the lower the burst. It is further predicted that peak overpressures on the ground at distances greater than 1,000 feet from ground zero will not be significantly different from those predicted for a surface burst at those distances. (See Chapter III).

2.4 Thermal Effects.

2.41 General :

One of the most import differences between atomic and HE explosions is the percentage of thermal radiation emitted at the time of detonation. The very high temperature of the atomic explosion results in a large proportion of its energy being dissipated by thermal radiation. For an airburst weapon approximately one-third of the total bomb energy appears in the form of thermal radiant energy. This enormous amount of energy being liberated in a small volume results in a hot gaseous bubble called the fireball, as described. The fireball expands rapidly in size with a corresponding decrease in temperature. After approximately three seconds, the fireball for a 20 KT burst will cool to such a degree that it will no longer radiate significant amounts. The quality of the radiation will vary with the fireball surface temperature; i.e., more ultraviolet at higher temperatures and more infrared at lower temperatures. As will be described below, the great majority of the energy will be in the visible and infrared region.

2.42 Thermal Energy Release Versus Time :

a. As a result of the interrelated mechanisms of energy transport, the fireball surface temperature undergoes an unusual change. Figure No. 2.42a presents the relationship between the fireball surface temperature, radius and time for the first 10 seconds of a 20 KT airburst. The surface temperature will scale according to Equation 2.3 below:

$$\frac{T_x}{T_{20}} = \left(\frac{W_x}{W_{20}}\right)^{1/3} \quad \text{: at any given time} \qquad (2.3)$$

where T is surface temperature at any time.

Example:

Given: From Figure 2.42 the surface temperature of the fireball from a 20 KT bomb (Air Burst) at one (1) second after detonation is 5,400° K.

Find: The surface temperature of the fireball from a 160 KT bomb (Air Burst) at one (1) second after detonation.

Solution:

$$T_{160} = 5400\,(8)^{1/3} = \underline{\underline{10,800.}} \quad \underline{\text{ans}}$$

The fireball radius will scale according to Equation 2.4

$$\frac{R_x}{R_{20}} = \left(\frac{W_x}{W_{20}}\right)^{1/3} \qquad (2.4)$$

where R = Radius (feet) of the fireball from the

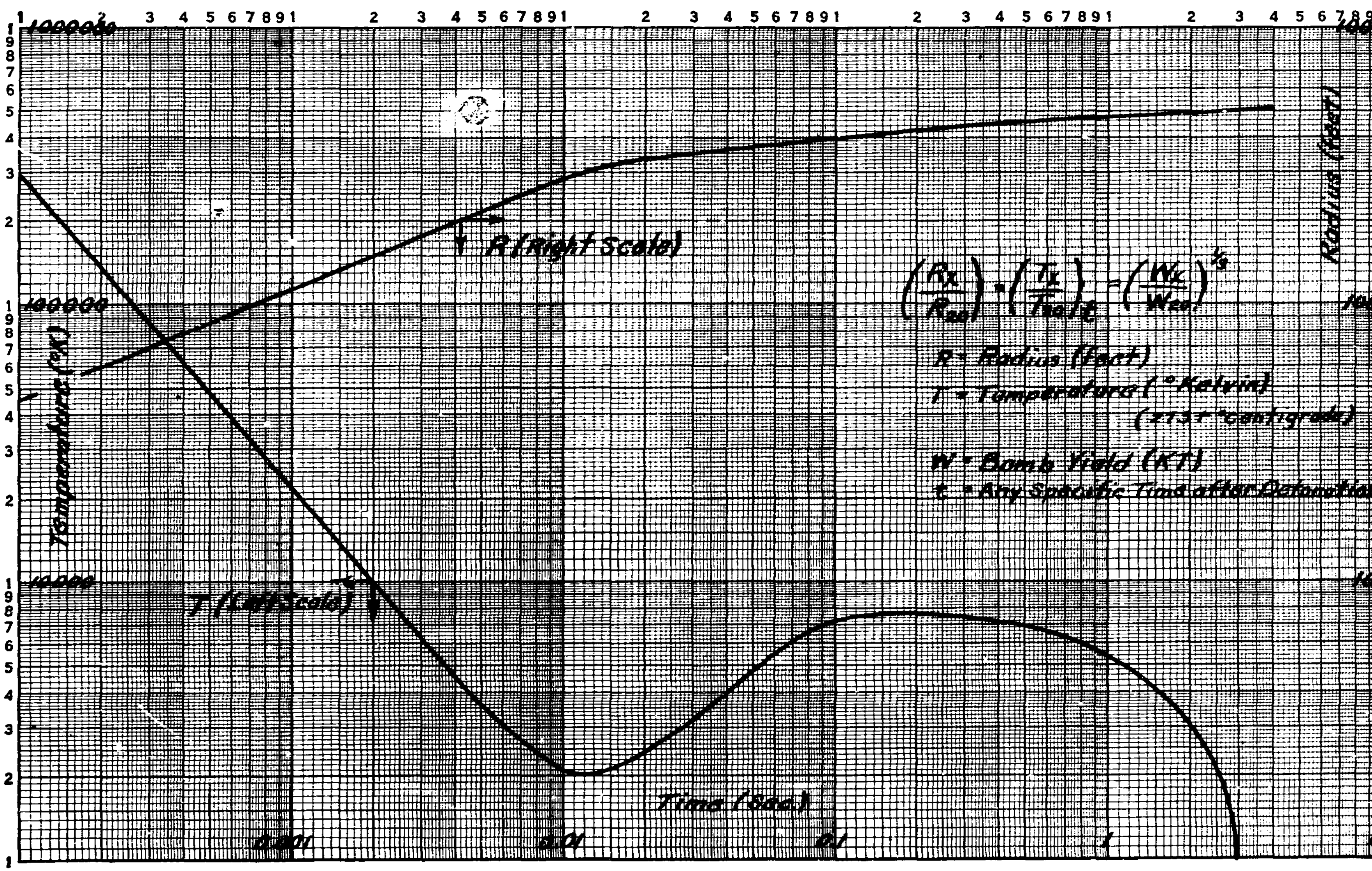

Figure 2.42 Surface Temperature and Radius of Fireball as a Function of Time after Explosion of a 20KT Air Burst Weapon

bomb at time t.

Example:

Given: From Figure 2.42 the radius of the fireball from a 20 KT bomb in air is 480 feet at one (1) second after detonation.

Find: The radius of the fireball from a 160 KT bomb in air at one (1) second after detonation.

Solution:

$$R_{160} = 480\ (8)^{1/3} = \underline{\underline{960.}}\ \underline{\text{ans}}$$

b. The thermal energy flux which arrives at a particular point is measured in calories per square centimeter per second. When the total thermal radiation energy arrives over a short-time interval which is the case with an atomic explosion, the total energy received is a very useful unit of measure. In Figure No. 2.42b is shown the percentage of the total thermal energy which will be received as a function of time. This percentage will scale according to Equation 2.5 below:

$$\frac{t_x}{t_{20}} = \left(\frac{W_x}{W_{20}}\right)^{1/3} \quad \text{: for same percentage.} \tag{2.5}$$

where: t_{20} is the time at which a given percentage is received from a 20 KT weapon.

t_x is the time for the same percentage from a W_x KT weapon.

Example:

Given: From Figure No. 2.43, 88% of the total thermal radiation is received from an air burst of a

20 KT weapon at two (2) seconds after detonation.

Find: The time at which 88% of the total thermal radiation is received from a 200 KT weapon.

Solution:

$$t_x = 2(10)^{1/3} = \underline{\underline{4.4 \text{ sec.}}} \quad \underline{\text{ans}}$$

c. The thermal radiant energy emitted from the fireball consists of a very short time pulse of visible light rich in ultraviolet followed by a relatively much longer time pulse of visible and infrared light. This second pulse will contain approximately 99% of all the thermal energy emitted.

2.43 Atmospheric Attenuation :

a. Except for being much nearer, the fireball from an atomic explosion is very similar to the sun in many respects; thus, the absorption and scattering of the bomb's thermal rays will be similar t9 that for the sun. That proportion reaching the earth, of the thermal radiation emitted from a particular atomic bomb, will depend on the distance involved and the intervening atmosphere through which the thermal rays must pass. The energy which is emitted as thermal radiation will consist of ultraviolet, visible and infrared light, which, because of the absorption of the ultraviolet and infrared by air, and water vapor, will consist mainly of visible light at the longer and more important ranges.

b. The amount of atmospheric absorption is very important and may be related for convenience to the "visibility." Here visibility is defined as the horizontal distance at which a large dark object can

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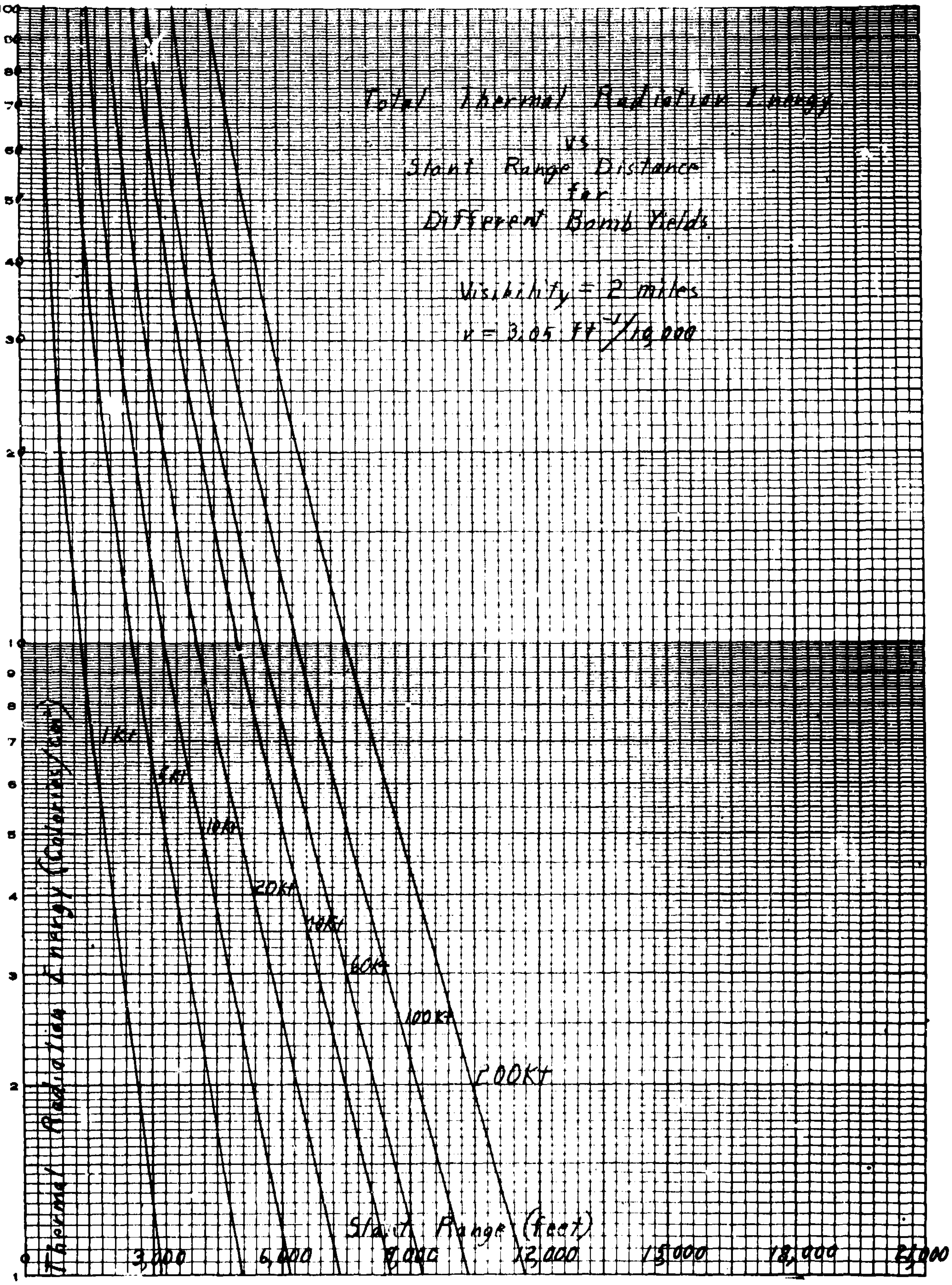

Figure 2.3b(1)

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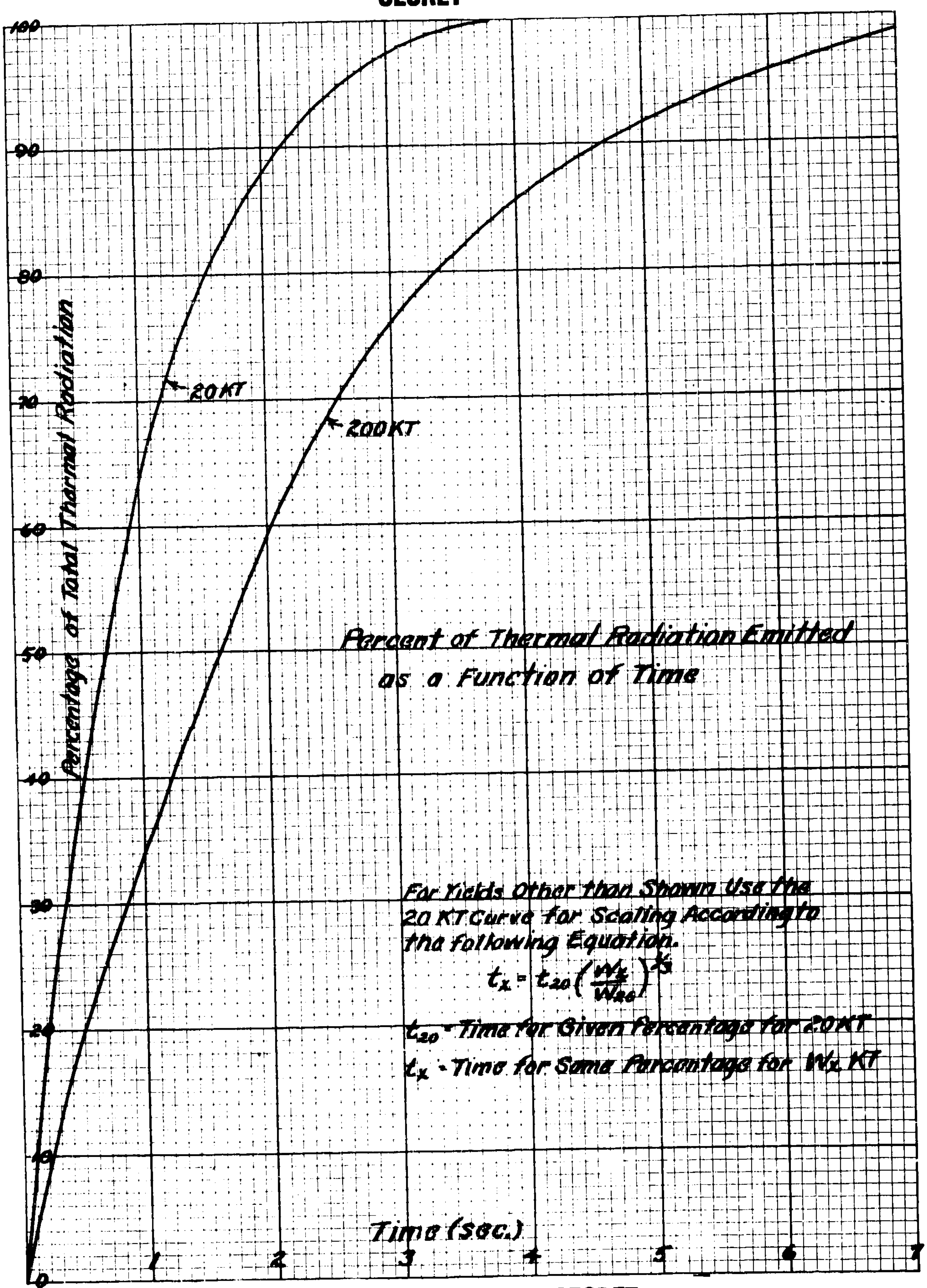

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Figure 2.A3

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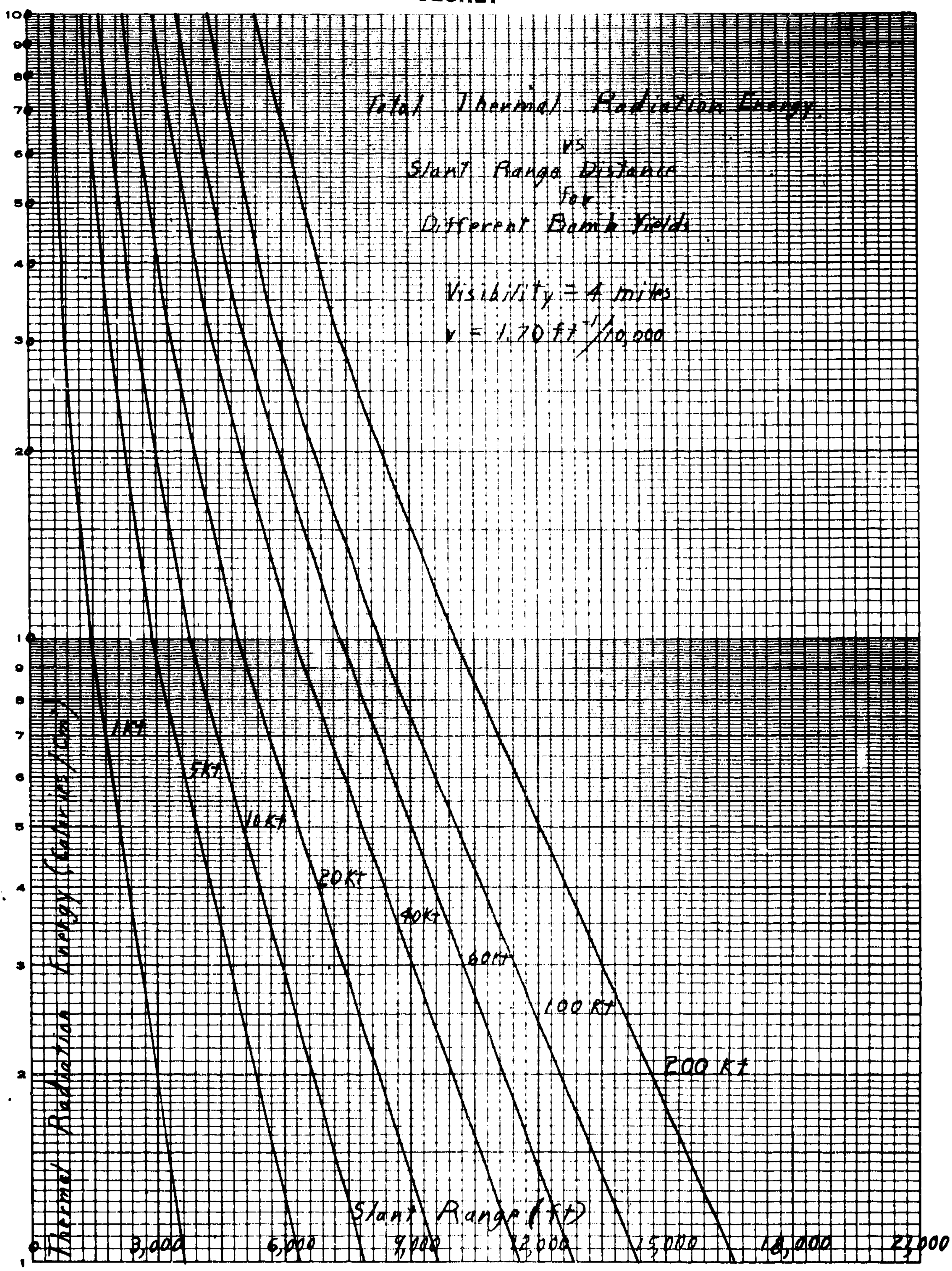

Figure SECRET
2.43 b(2)

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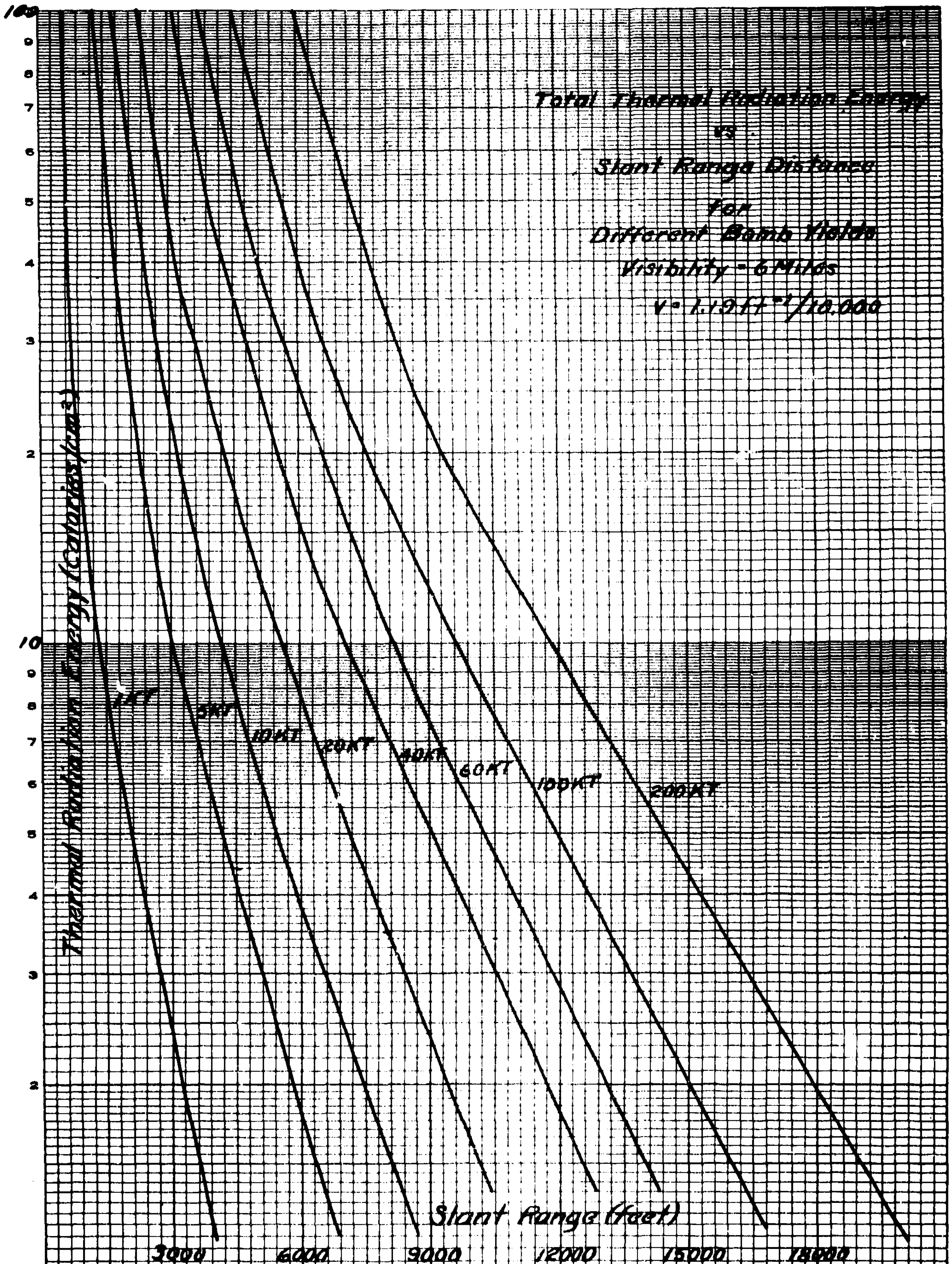

Figure 2.43 b (3)

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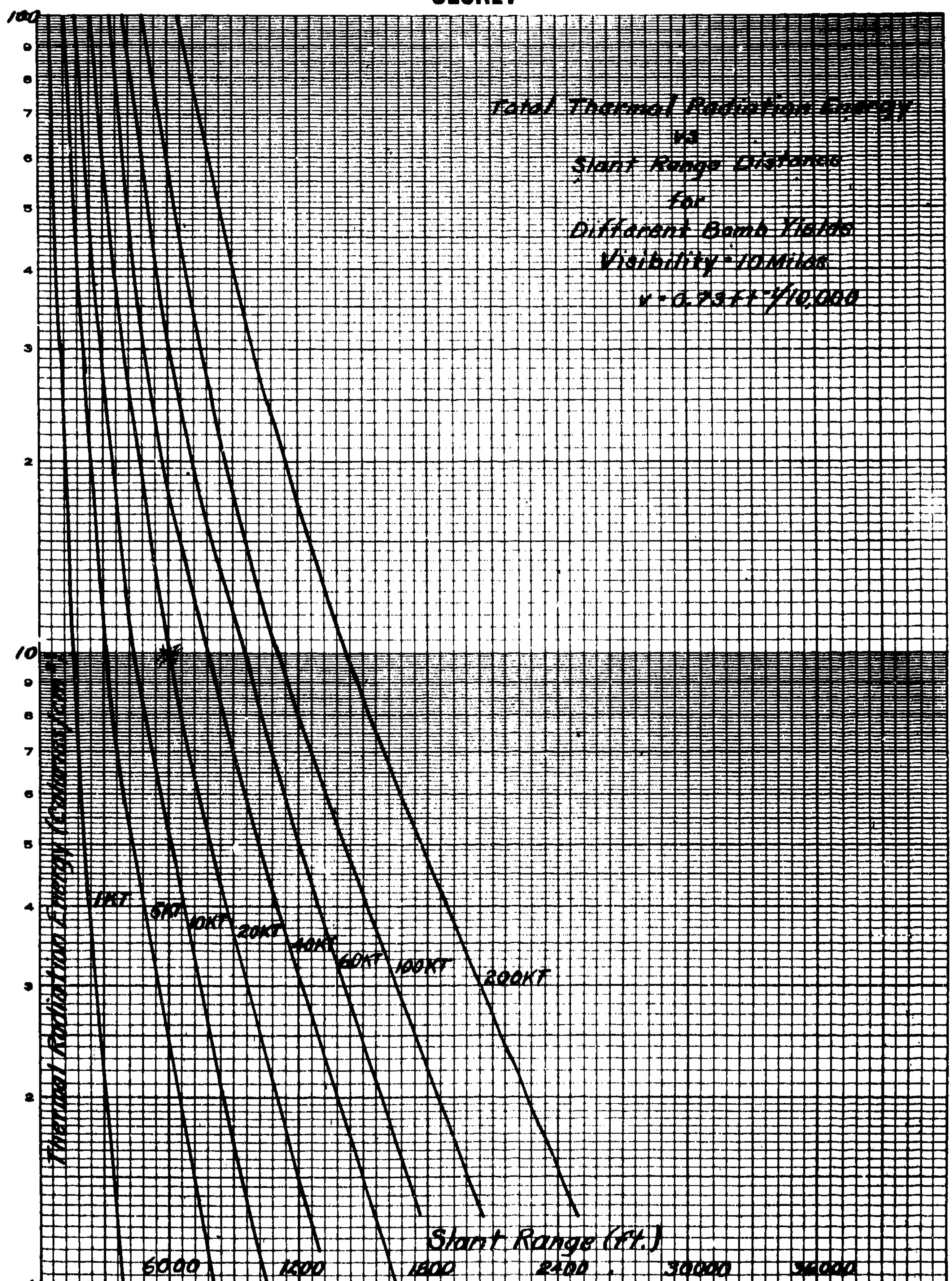

Figure 2.43 b(a)

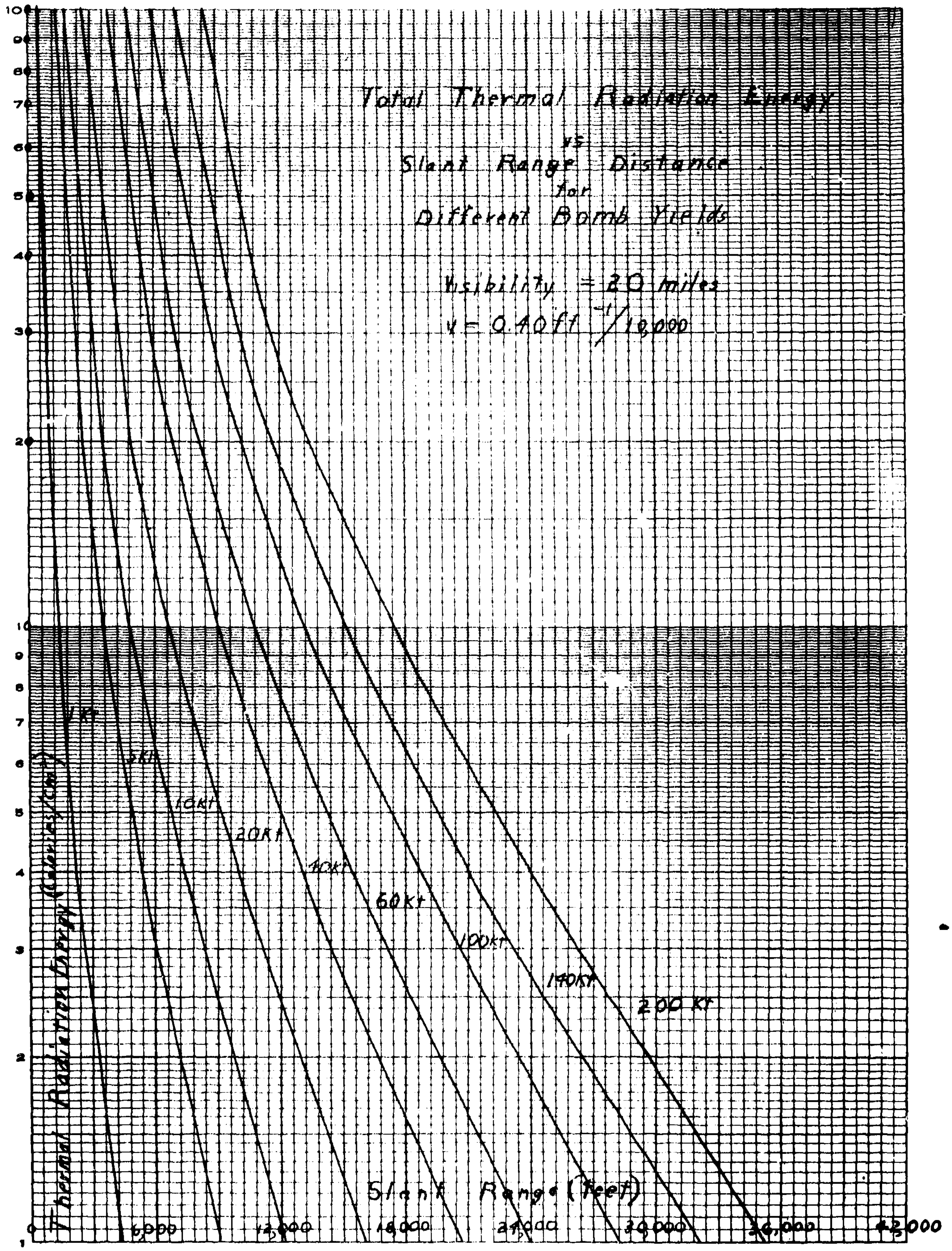

Figure 2436(5)

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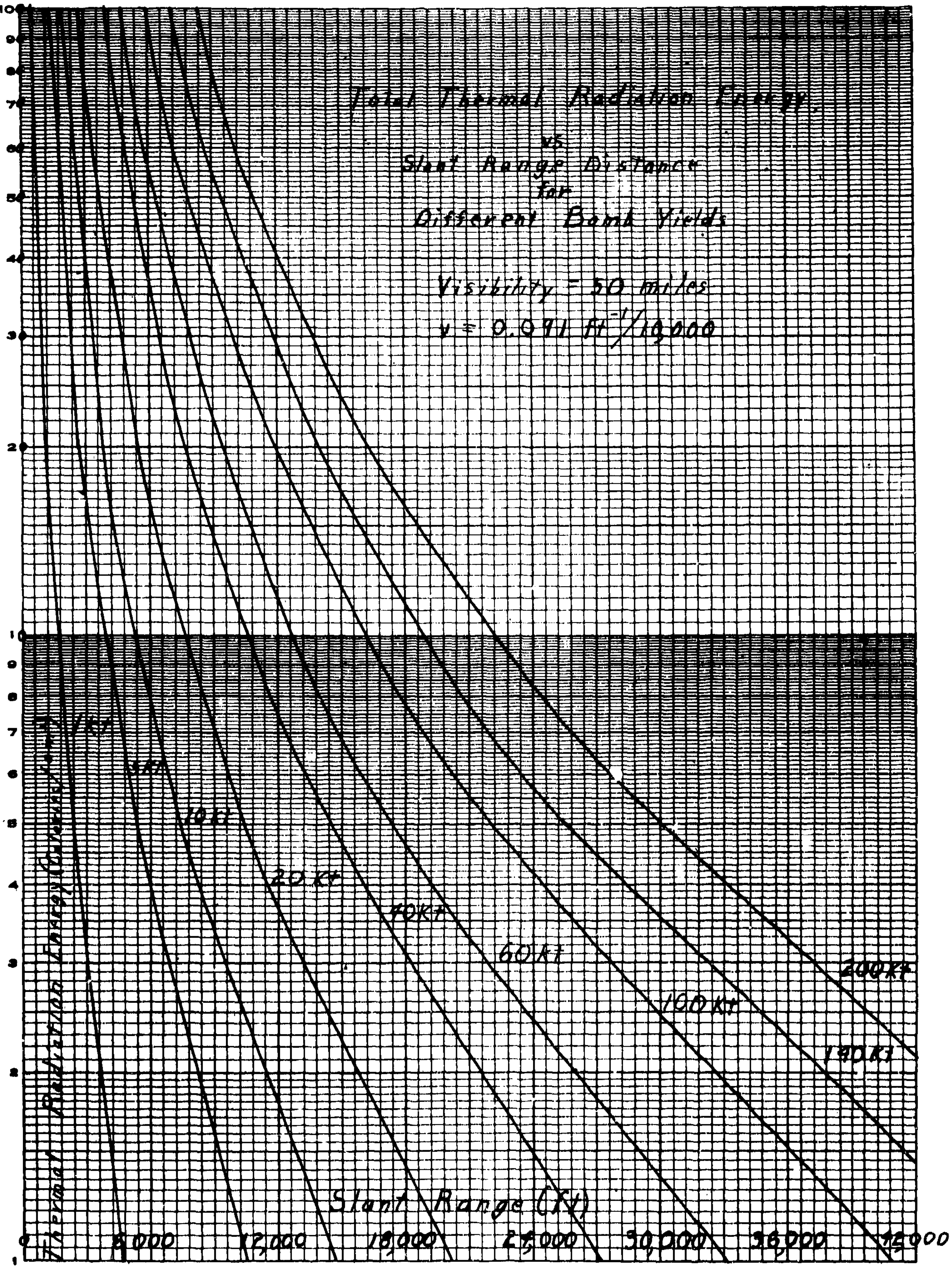

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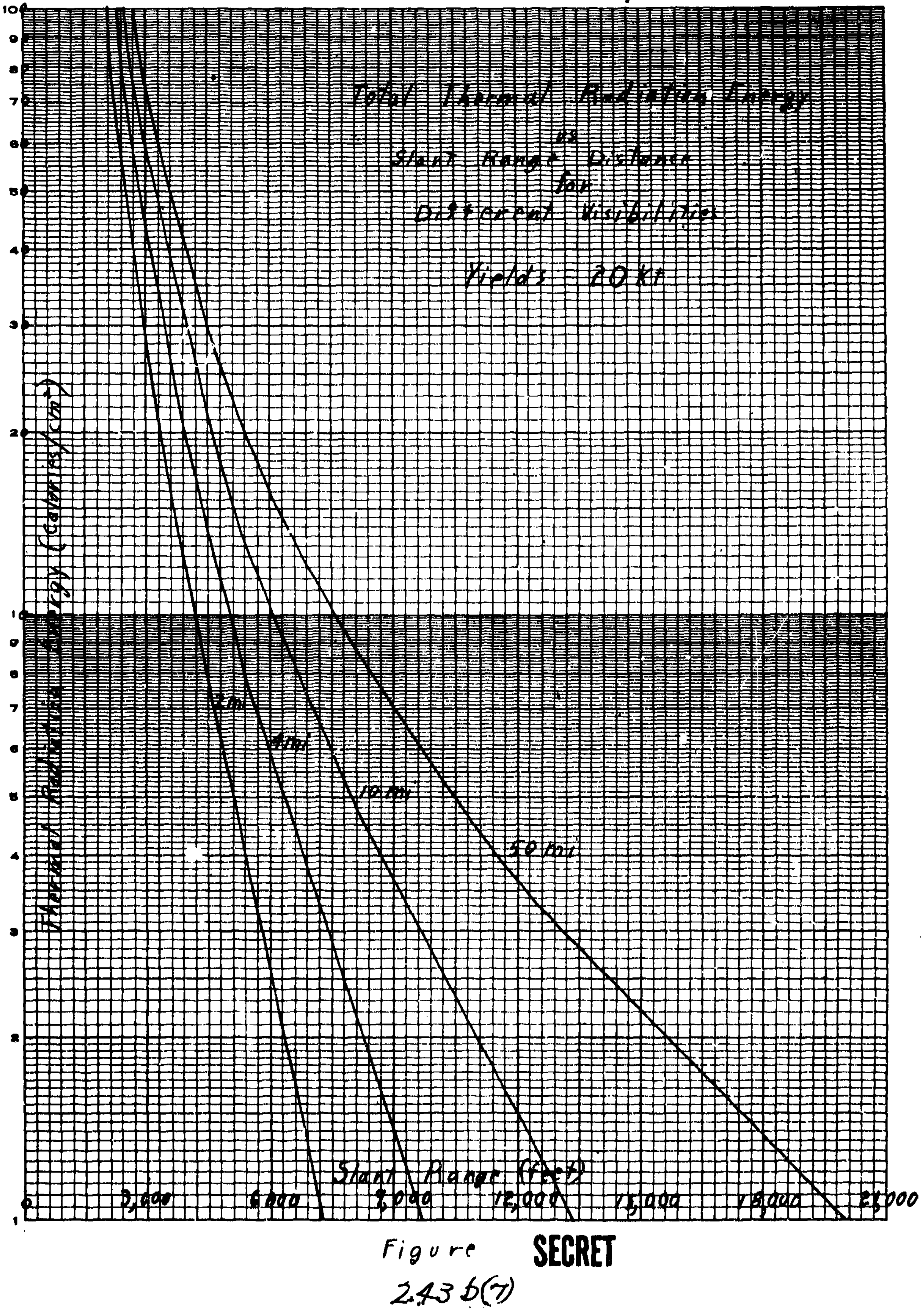

Figure 2.43 b(7)

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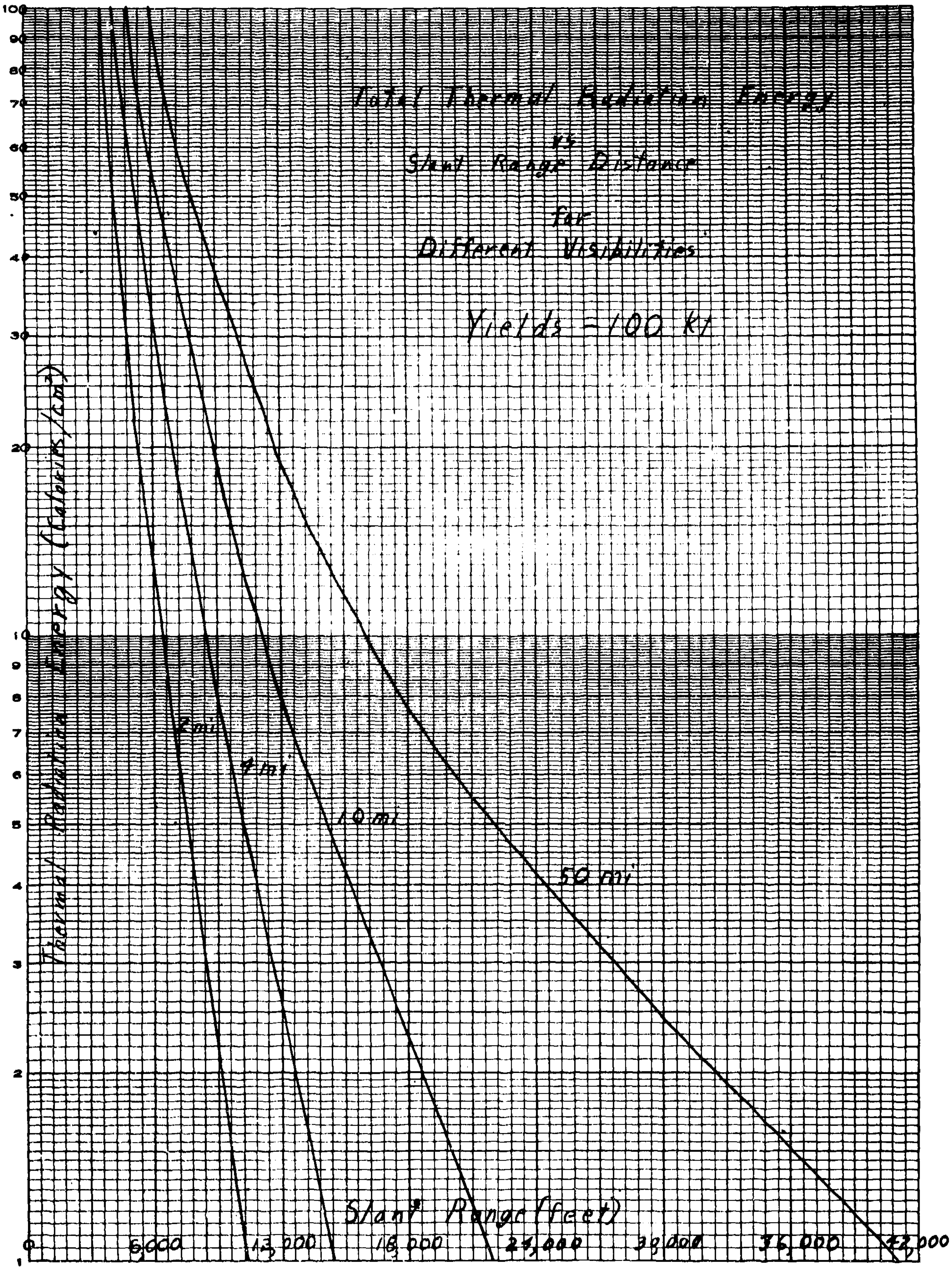

Figure
2.43 b (8)

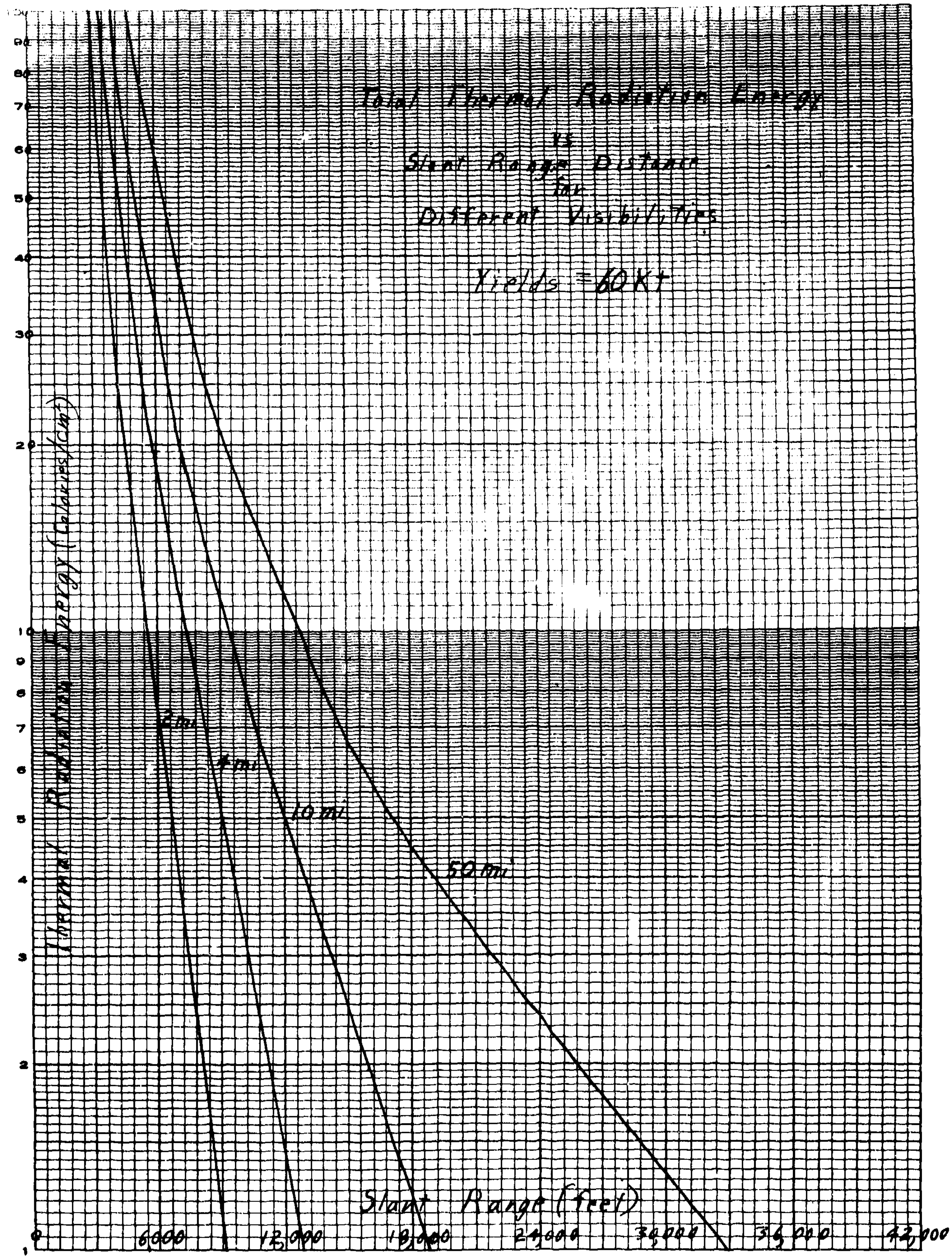

Figure 2.43 b(9)

be seen against the sky at the horizon. Figures 2.43b(1) through 2.43b(9) show the relationship between the bomb yield, distance, calories/cm^2 received, and the visibility. These factors are related by the scaling law given below in Equation 2.6.

$$\left(\frac{d_x}{d_{20}}\right)^2 = \frac{W_x}{W_{20}} e^{v(d_x - d_{20})} \qquad (2.6)$$

where:

d is distance at which a specified thermal energy will be received.

v is attenuation coefficient

c. Figure No. 2.43c is included to show the relation between visibility in miles and the attenuation coefficient. Note that equation 2.6 above is for a particular energy received, where energy is measured in calories per square centimeter. On a clear day, approximately .025 cal/cm^2 are received at the earth from the sun.

2.5 Nuclear Radiation Effects

2.51 General :

a. When an atomic bomb is exploded, part of the energy of the explosion is released in the form of nuclear radiations consisting of gamma rays, neutrons and alpha and beta particles. The neutrons are generated in the fission reaction, the gamma rays and beta particles are emitted by the radioactive fission products, and the alpha particles are emitted by any plotonium or uranium that is not used up in the explosion.

b. The useful effects of the nuclear radiations vary with the medium in which the bomb is detonated and will be discussed in detail under the specific conditions of air, surface, underground, and underwater bursts. Neutrons are all produced in the first second after detonation while gamma radiations will be emitted from both the initial fireball and from possible contamination. Since the ranges of the alpha and beta particles are short, they are of little military importance and need be considered only when direct contamination occurs. For the purposes of discussing the effects, initial radiation is defined as that nuclear radiation which is delivered in the first few seconds after the bomb detonation, and residual radiation as that which is delivered thereafter. The latter is of interest principally from the standpoint of ground, water and atmospheric contamination.

c. For the purposes of measuring the gamma radiation effects, the roentgen unit (r) is used to describe the total dosage or exposure received and roentgens per hour to describe the rate at which this dosage is received. These units can be related directly to the physiological damage to personnel. It is noted that one gram of radium will produce 0.84 roentgens per hour at a distance of 3 feet.

2.52 Initial Radiation :

a. In an air burst the initial radiations produce the only militarily significant effects of the nuclear radiation. Figure 2.52a shows the initial gamma ray dosage versus slant range distance (distance from bomb to target) for air bursts of different yields. It should be emphasized that these distances are slant ranges from the point of

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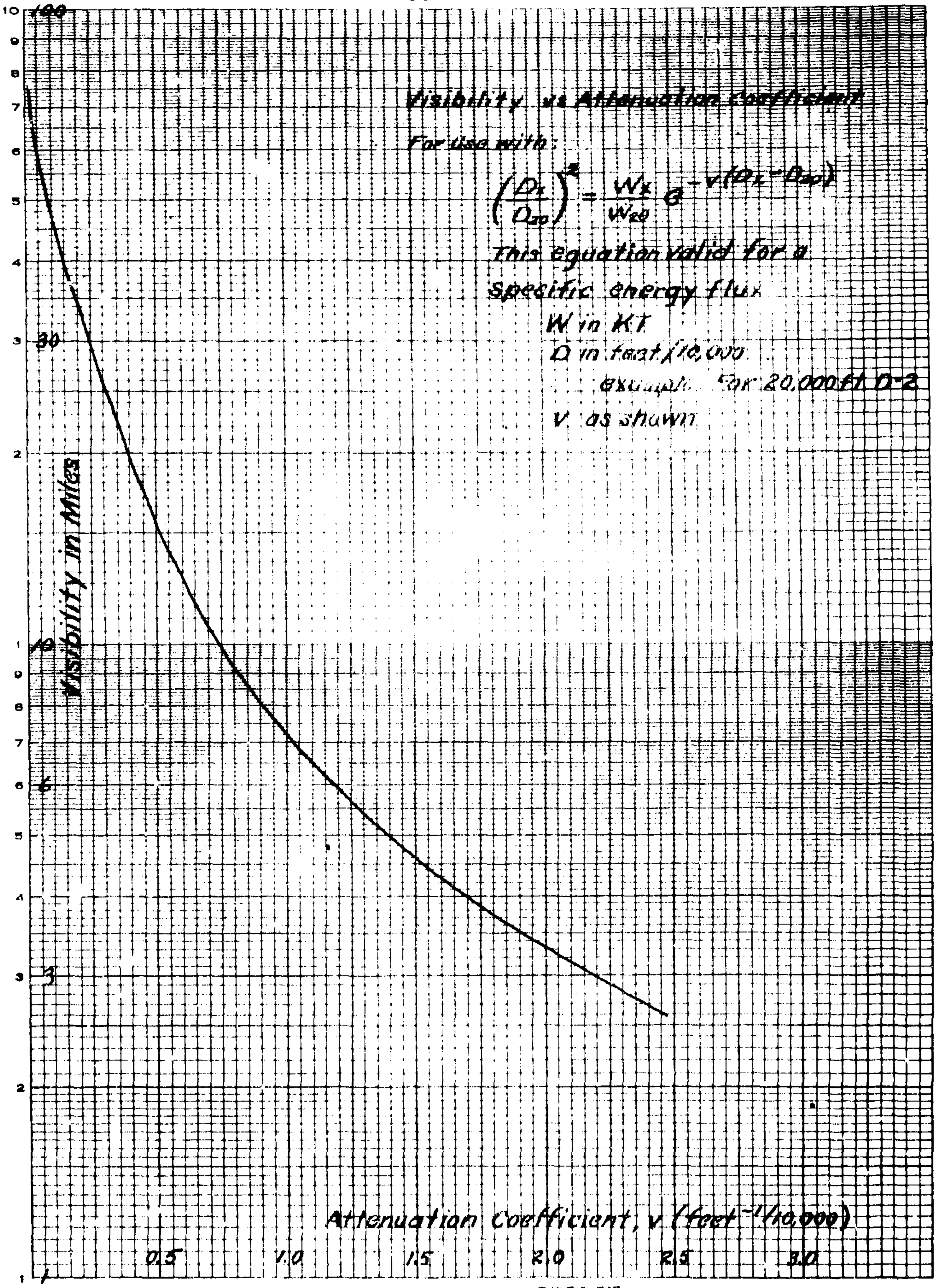

Figure 2A3c SECRET

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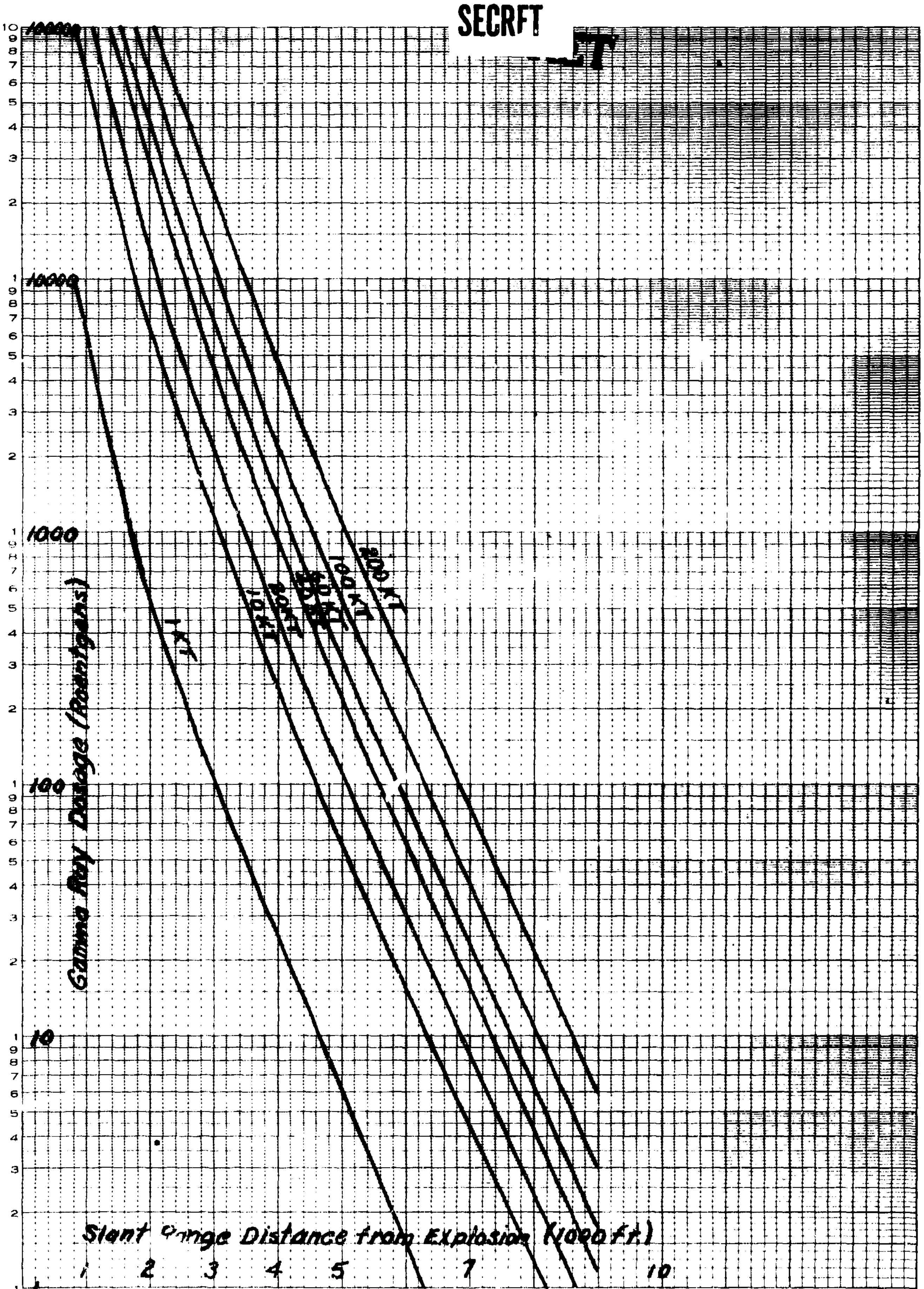

Figure 2.52a Initial Gamma Ray Dosage vs. Slant Range Distance (Air Burst Bombs)

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detonation. To determine the dosage versus distance for bombs of other yields from this curve, apply the scali[illegible] w shown in equation 2.7 below:

$$\frac{r_1}{W_1} = \frac{r_2}{W_2} \qquad \text{: at the same distance} \tag{2.7}$$

r = dosage in roentgens

W = yield in KT

Example:

Given: From Figure 2.52a the distance at which a target will receive 10r from a one (1) KT weapon, is 4,650 feet.

Find: The gamma radiation dosage a target will receive from a 10 KT weapon at that distance.

Solution:

$$r_{10} = \frac{10}{1}(10) \qquad \underline{\underline{100\ r.}} \quad \underline{\text{ans}}$$

Alternate Solution:

From Figure 2.52a the gamma radiation dosage received at a target 4,650 feet from a 10 KT weapon is 100r.

b. About one-half the initial gamma radiation dosage from an air burst is obtained in the first second after detonation. Figure 2.52b shows the percentage of total initial gamma ray dosage received as a function of time after the detonation.

c. The amount of gamma radiation actually received on a target

is influenced by the amount of shielding between the target and the radiation source, since the intensity of the beam of gamma radiation is reduced as it passes through matter, it is useful to know the thickness of various materials required to produce a given reduction in incident dosage. The determining factor in the effectiveness of a shield is the weight of material between the source and the target. Although the thickness of material required to produce a given reduction will be less the greater the density of the shield material, lead is no better as a shield than an equal weight of earth. Figure 2.52c shows the fraction of the total incident dosage received as a function of shield thickness for water, earth, concrete, iron, and lead. If reductions greater than a factor of 10 are required, merely add the thickness for a factor of 10 to the thickness for whatever additional percentage reduction is required. However, when large reductions are desired, line of sight or shadow shielding may not be sufficient since a fraction of the radiation (as much as 10%) may be scattered and will arrive at the target from a different direction than from the point of detonation.

Example:

Given: At a distance of 4,650 feet, 50r are received from a 5 KT air burst.

Find: 1- The thickness of earth required to cut the dosage down to 25r.

2- The thickness of earth required to cut the dosage down to 1r.

Figure 2.52b Proportion of Total Dosage of Initial Gamma Radiation Received as Function of Time after Explosion

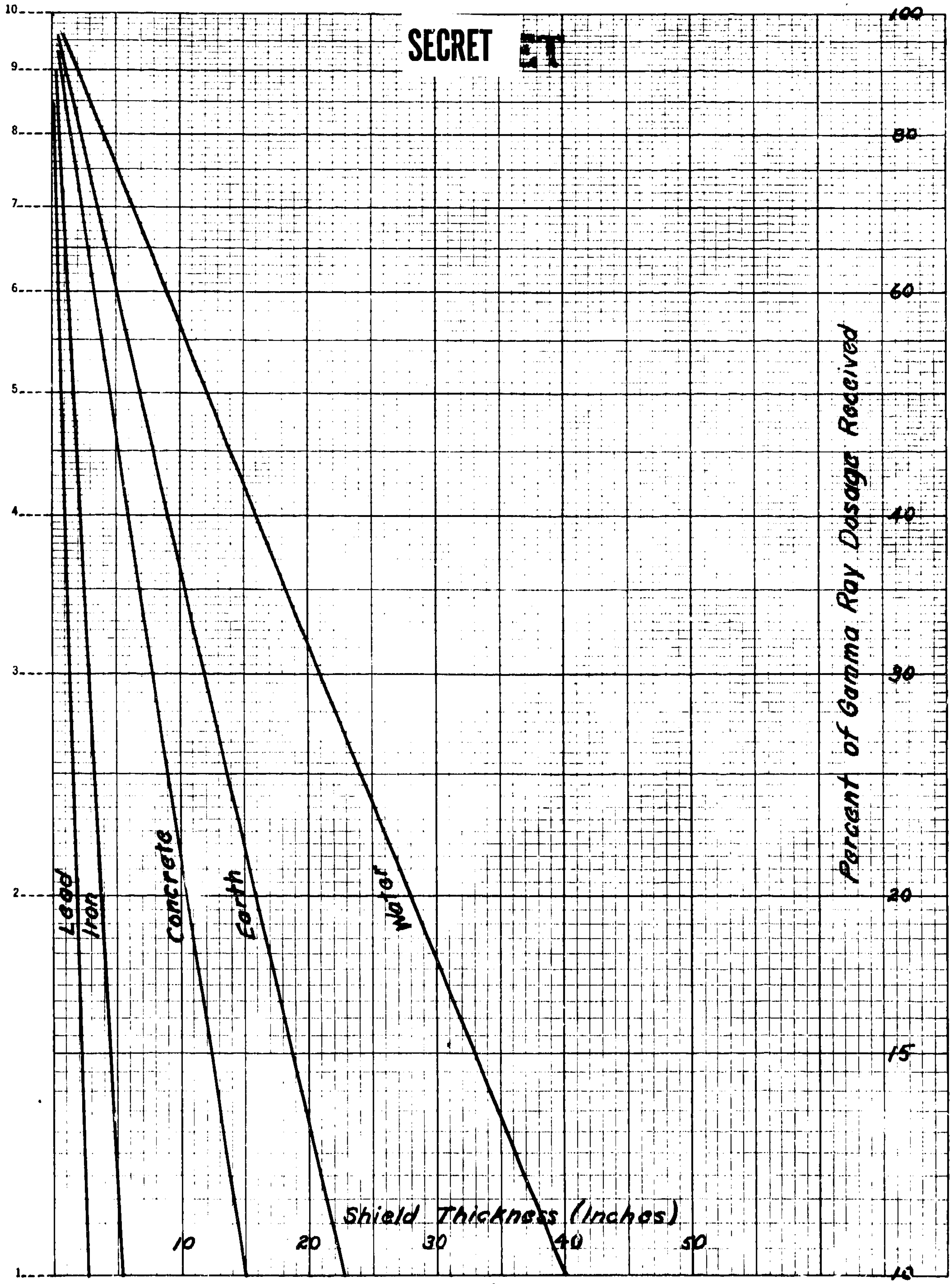

Figure 2.52c Percentage of Gamma Ray Dosage Received vs. Shield Thickness

Solution:

1- $\frac{25r}{50r}(100) = 50\%$

From Figure 2.52c, seven (7) inches of earth are required to reduce the dosage to 25r. ans

2- $\frac{1r}{50r} = 0.02$ or 2%

From Figure 2.52c, 23 inches of earth are required to reduce the dosage to 5r (10% reduction)

and, $\frac{1r}{5r}(100) = 20\%$

From Figure 2.52c, 16 inches are required to reduce the dosage from 5r to 1r. Therefore, 23 plus 16, or 39 inches of earth, total, are required to reduce the dosage from 50r to 1 r. ans

d. The effects of neutrons are of little military importance since the range of significant gamma ray dosages is far greater than that of the neutrons in almost all normal situations.

2.53 Residual Radiation :

a. The surface contamination effects of an air burst weapon are not significant since the bomb cloud carries all radioactive materials to high altitudes. By the time these can fall back to earth, dilution and radioactive decay will decrease the activity to a point that it will be of no military importance.

b. Since most of the radioactive materials are airborne, the radiation hazard produced by the atomic cloud may be great for some

time. The cloud size, rate of rise, and gamma radiation dose rates within it will vary with the yield of the bomb and the prevailing meteorological conditions. Since these variations cannot be accurately predicted, a typical case will be shown in Figure 2.53b to give an indication of the relative magnitude of these phenomena. A significant dosage of gamma radiation would be recieved by personnel flying through the cloud shortly after the detonation. However, the dose rate falls rapidly outside the cloud, although it would be measurable a mile or more away. This is an important consideration from the standpoint of post shot reconnaissance and in planning multiple drops.

Solution:

1- $\frac{25r}{50r}(100) = 50\%$

From Figure 2.52c, seven (7) inches of earth are required to reduce the dosage to 25r. ans

2- $\frac{1r}{50r} = 0.02 \text{ or } 2\%$

From Figure 2.52c, 23 inches of earth are required to reduce the dosage to 5r (10% reduction)

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Dup page

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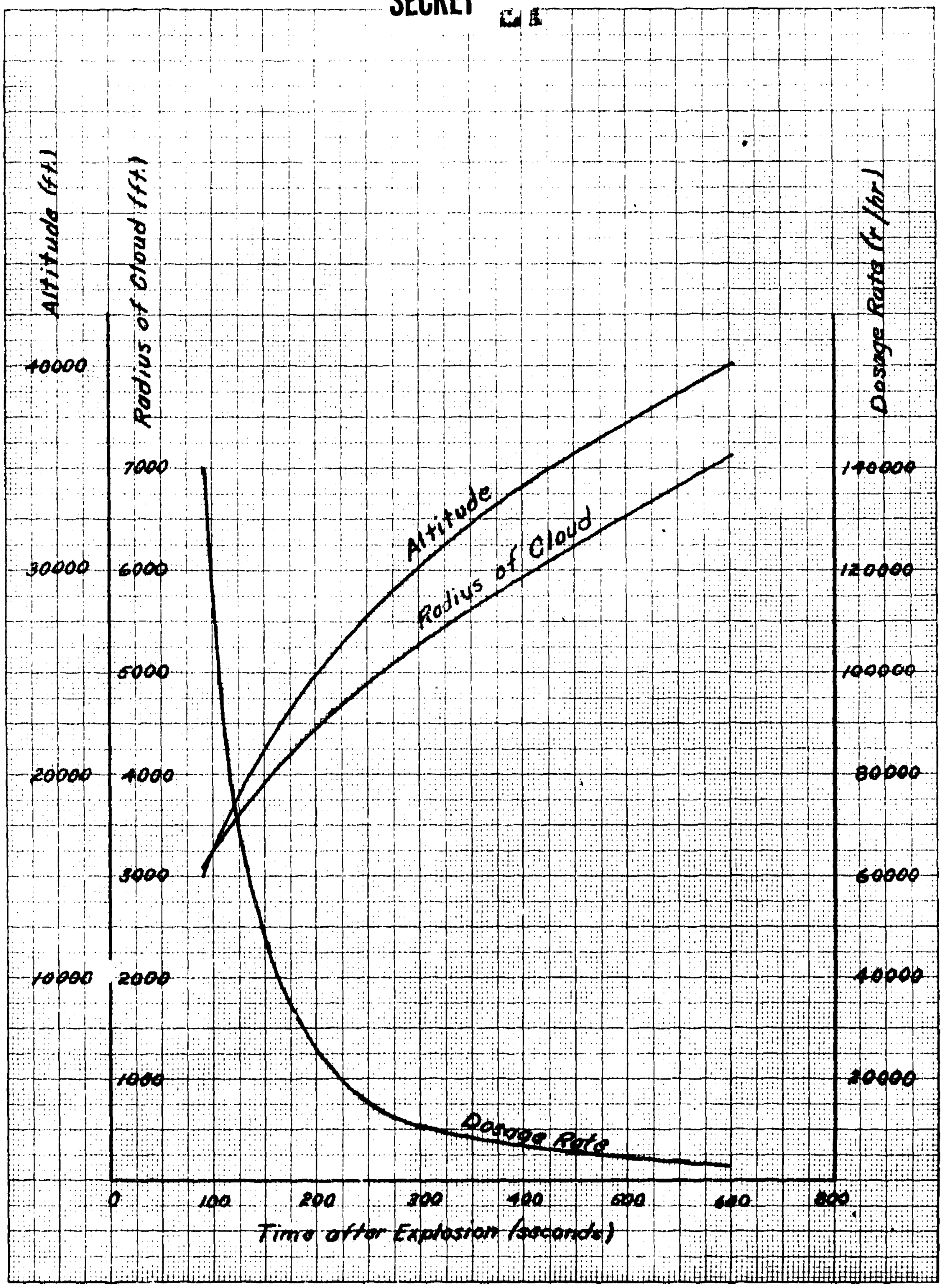

Figure 2.53b Properties of the Radioactive Cloud from a 20 KT Bomb

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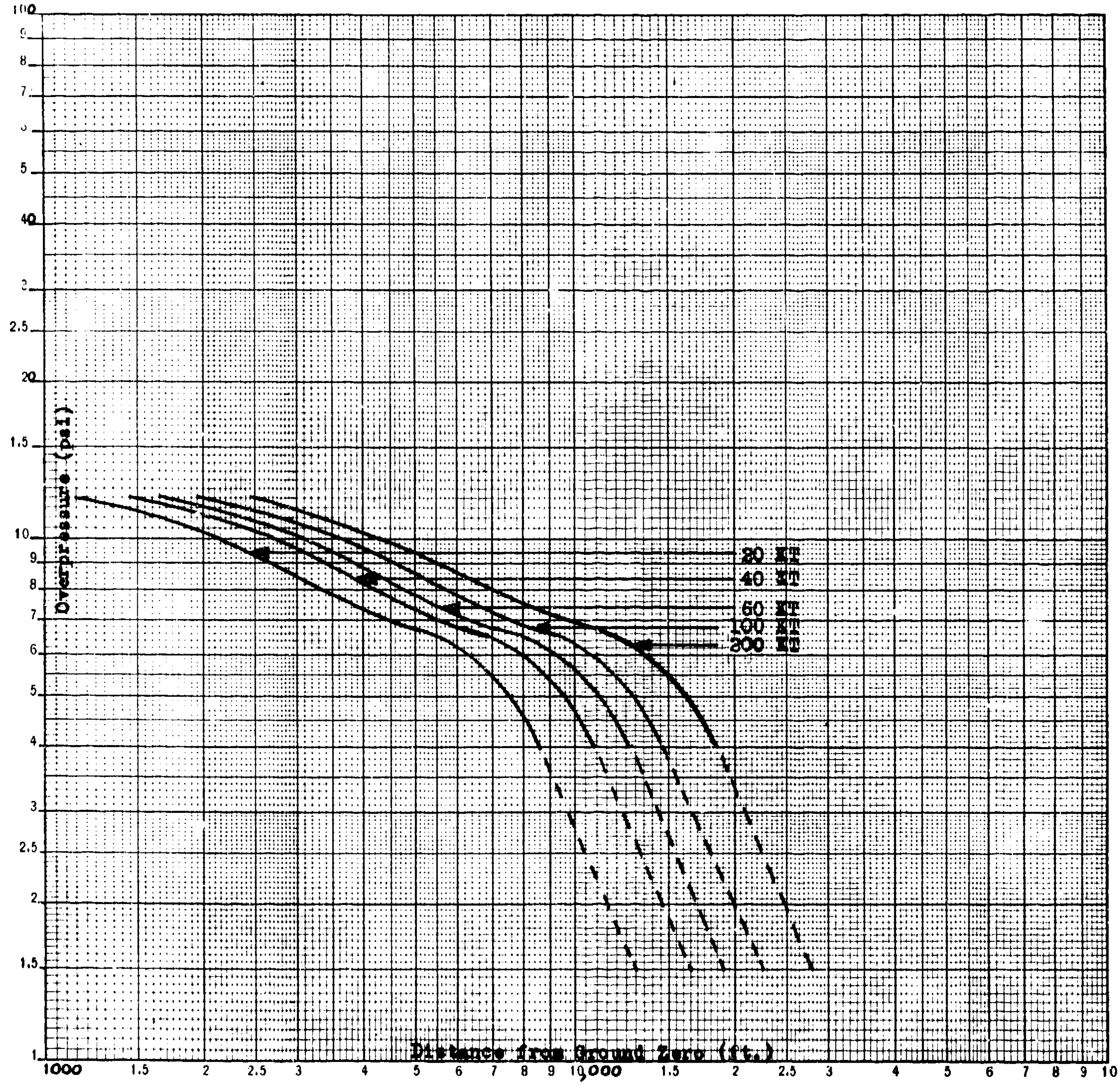

Fig. 2.6a. Air Pressure on Ground vs Distance from Ground Zero for various Kiloton Yields
(Optimum Height of Burst for 5 psi assumed; 1370 ft. for 1 KT Bomb)

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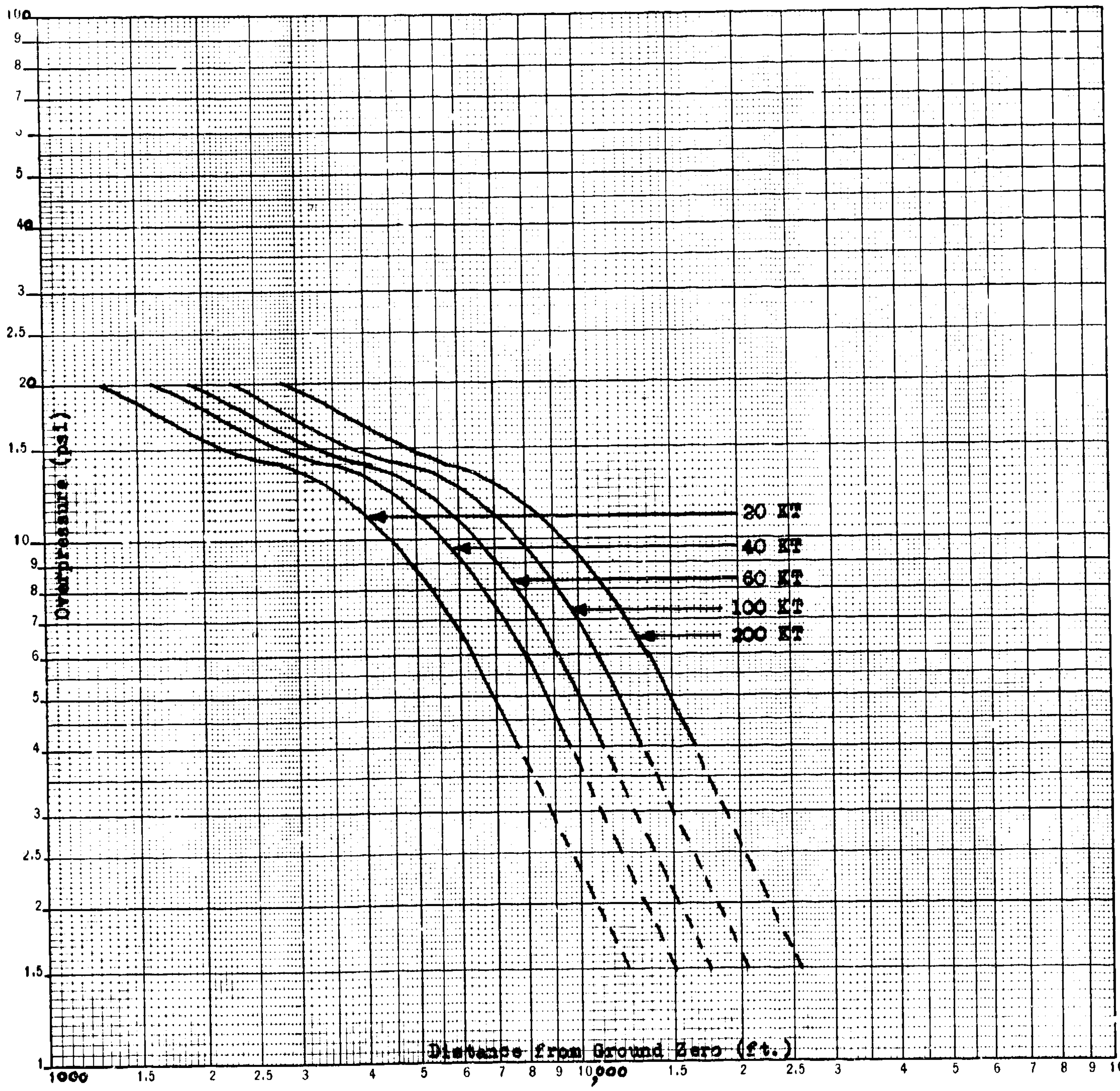

Fig. 2.6b. Air Pressure on Ground vs distance from Ground Zero for various Kiloton Yields
(Optimum Height of Burst for 10 psi assumed; 1000 ft. for 1 KT Bomb)

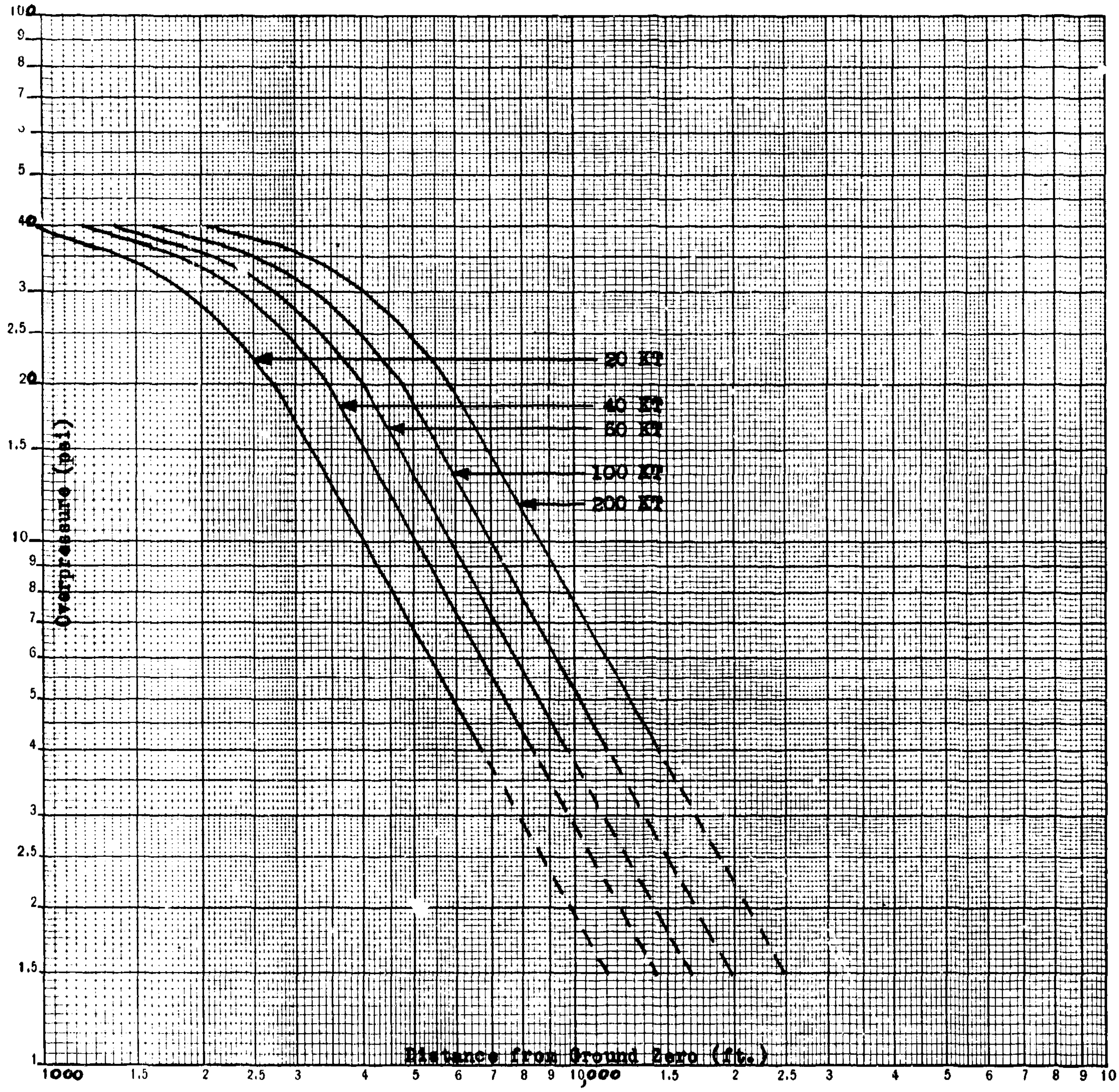

Fig. 2.6c. Air Pressure on Ground vs distance from Ground Zero for various Kiloton Yields
(Optimum Height of Burst for 20 psi assumed; 700 ft. for 1 KT Bomb)

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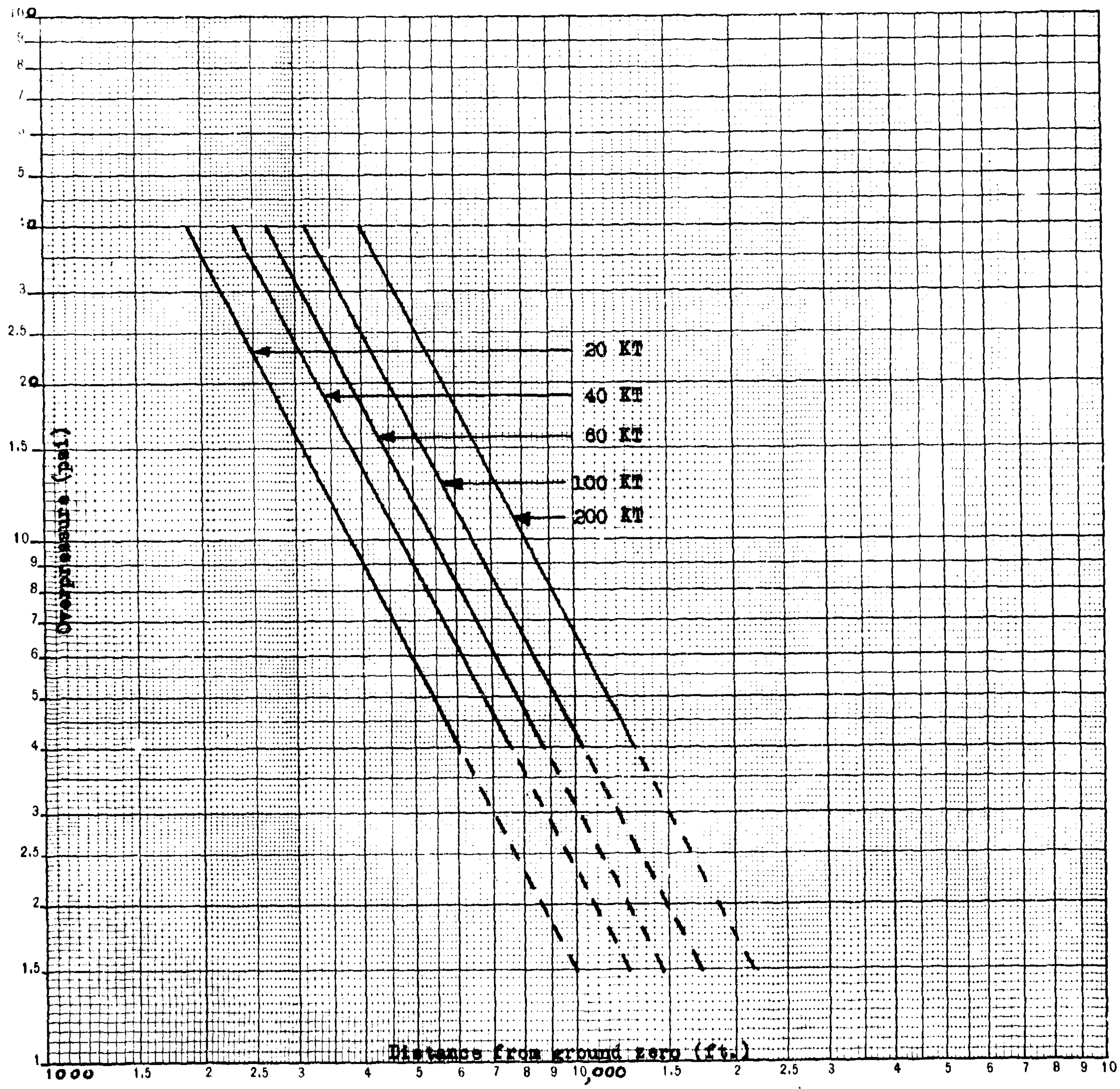

Fig. 2.6d Air Pressure on Ground vs Distance from Ground Zero for various kiloton yields.
(Optimum Height of Burst for 40 psi assumed; 485 ft. for 1 KT Bomb)

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CHAPTER III

THE SURFACE BURST : LAND

3.1 Brief Description of Surface Burst:

3.11 When an atomic bomb is detonated at the earth's surface, it will first appear as a sudden flash of light similar to the flash from the air burst. Shortly after detonation, a roughly hemispherical fireball will appear. As the ball of fire continues to grow in the air, a shock wave will develop as described in Chapter II. Meanwhile, pressures on the order of hundreds of thousands of psi will be exerted on the earth's surface causing the formation of a crater, to be described later. In addition it is anticipated that a considerable quantity of earth will be vaporized by the intense heat.

3.12 During the expansion of the hemispherical ball of fire a dust skirt will probably appear at its base, traveling outward at great velocity. Shortly thereafter the hot gases in the fireball will begin to rise forming a cloud. The uprush of air will carry with it radioactive material comprised of fission products, unfissioned bomb material, and irradiated earth, etc., As this cloud of material continues to rise, it will probably change in shape and become almost spherical. It is estimated that the cloud from a 20 KT weapon will reach a maximum height of 20,000 to 25,000 feet.

3.2 Energy Distribution

The partition of energy for a surface burst (on land) of an atomic

bomb has been estimated as follows:

Air Blast		35%
Cratering and Column		10%
Ground Shock		15%
Earth Fusion and Thermal Radiation		25%
Earth Fusion	15%	
Thermal Radiation	10%	
Nuclear Radiation		15%
Instantaneous Gammas and Neutrons	5%	
Residual Contamination	10%	

3.3 Air Blast

3.31 Peak overpressures in the vicinity of the point of detonation will be very high, resulting in over-destruction of surface targets nearby. A graph of peak overpressures versus distance is given for various KT yields. (See Figure No. 3.31). Note that these curves begin at an overpressure of 100 psi. It is pointed out that these overpressures are scaled from small charges of TNT. No full scale data is available at this time.

3.32 For a true surface burst (zero feet height of burst) there is no formation of a Mach stem. The air blast overpressures from such a burst theoretically should be equivalent to the overpressures obtained from a bomb of twice the yield at any distance in free air, based on the assumption of a perfectly reflecting surface. However, since a considerable portion of the bomb's energy is absorbed by the earth, the

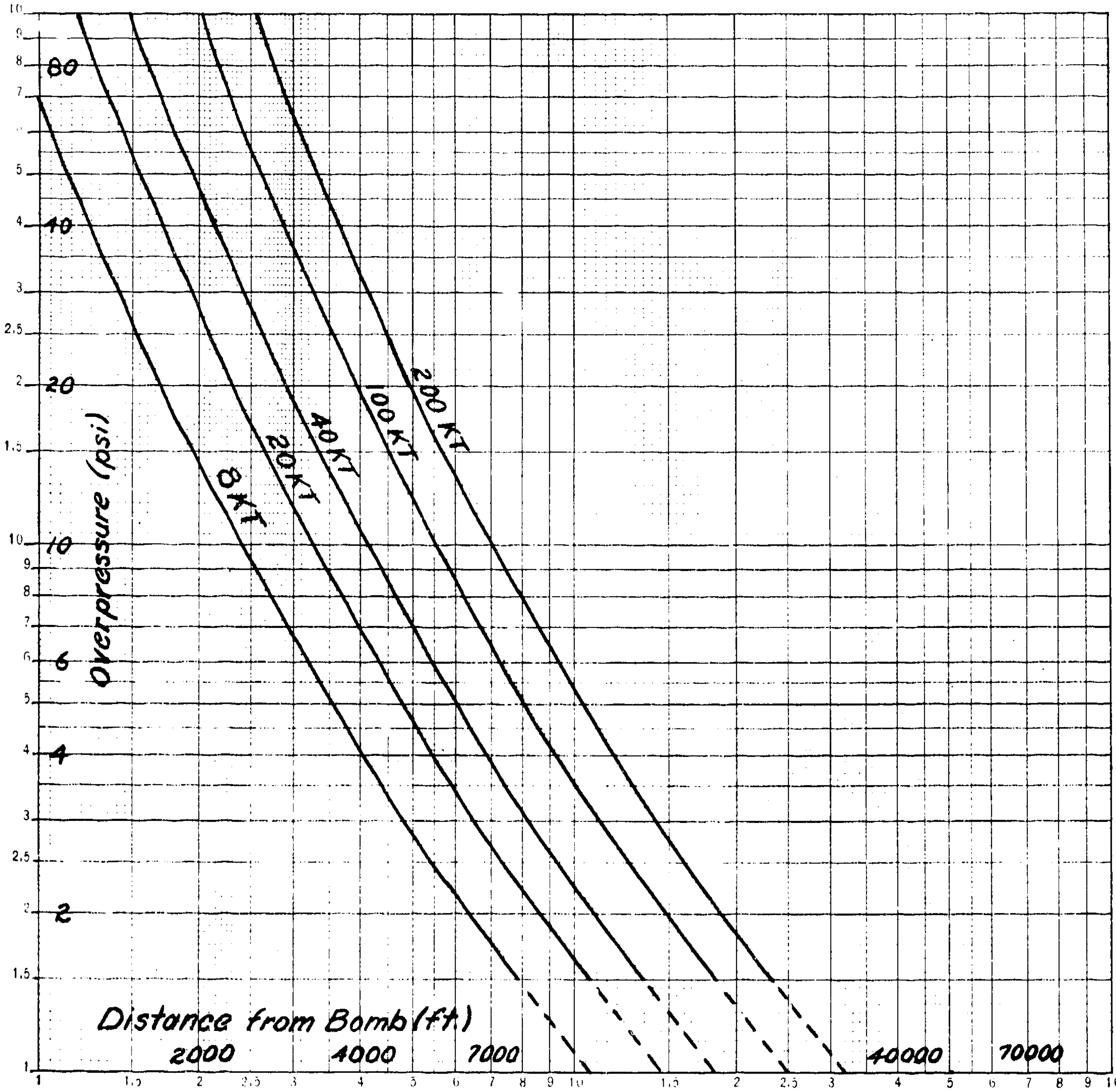


Figure 3.31 Airblast Overpressure on Ground vs. Distance from Bomb for Various KT Yields (Burst at 0-50' Altitude)

overpressures measured at any distance from a surface burst are predicted to be equivalent to those from bombs of 1.5 that yield in free air. Then the range at which a given overpressure may be predicted can be computed from equation 2.1.

Example:

Given: The range at which 10 psi is obtained from a 20 KT bomb in free air is 2,800 feet.

Find: The range at which 10 psi would be experienced from a surface detonation of the same weapon.

Solution: 1.5 x 20 = 30

$$d_{30} = 2800(1.5)^{1/3} = \underline{\underline{3200\ ft}}$$

ans

Alternate Solution:

From Figure 3.31 the range at which 10 psi is obtained from a surface detonation of a 20 KT bomb is approximately 3,200 feet. ans

3.4 Cratering and Column

3.41 Crater Dimensions :

a. Crater diameters in sand versus KT yields are given for four positions above and below the earth's surface (see Figure No. 3.41a). For loam, crater diameters should be 10% larger, and for clay, crater diameters should be 20% larger, than for sand.

b. Depths of craters in sand are plotted versus KT yield for the same positions on Figure 3.41b. Depths of craters in clay will be approximately 15% larger than those in sand and depths of craters in loam will be approximately 5% larger.

c. ~~Both~~ the crater diameters ~~and crater depths~~ should be reduced materially (one-sixth) by fall-back. It should be remembered that the information presented here has been scaled from relatively small charges of TNT.

d. A mound of earth will be formed around the edge of the crater by passive earth failure and fall-back. This mound is called the lip of the crater. The height of the lip will be approximately one-fourth of the depth of the crater, and the outer edge of the lip will extend to approximately twice the diameter of the crater. (See Figure 3.41d).

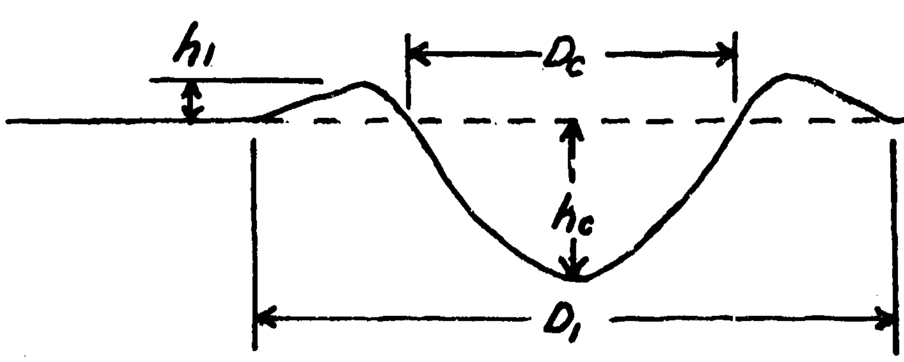
Figure 3.41d

h_l = height of lip

h_c = depth of crater

D_c = diameter of crater

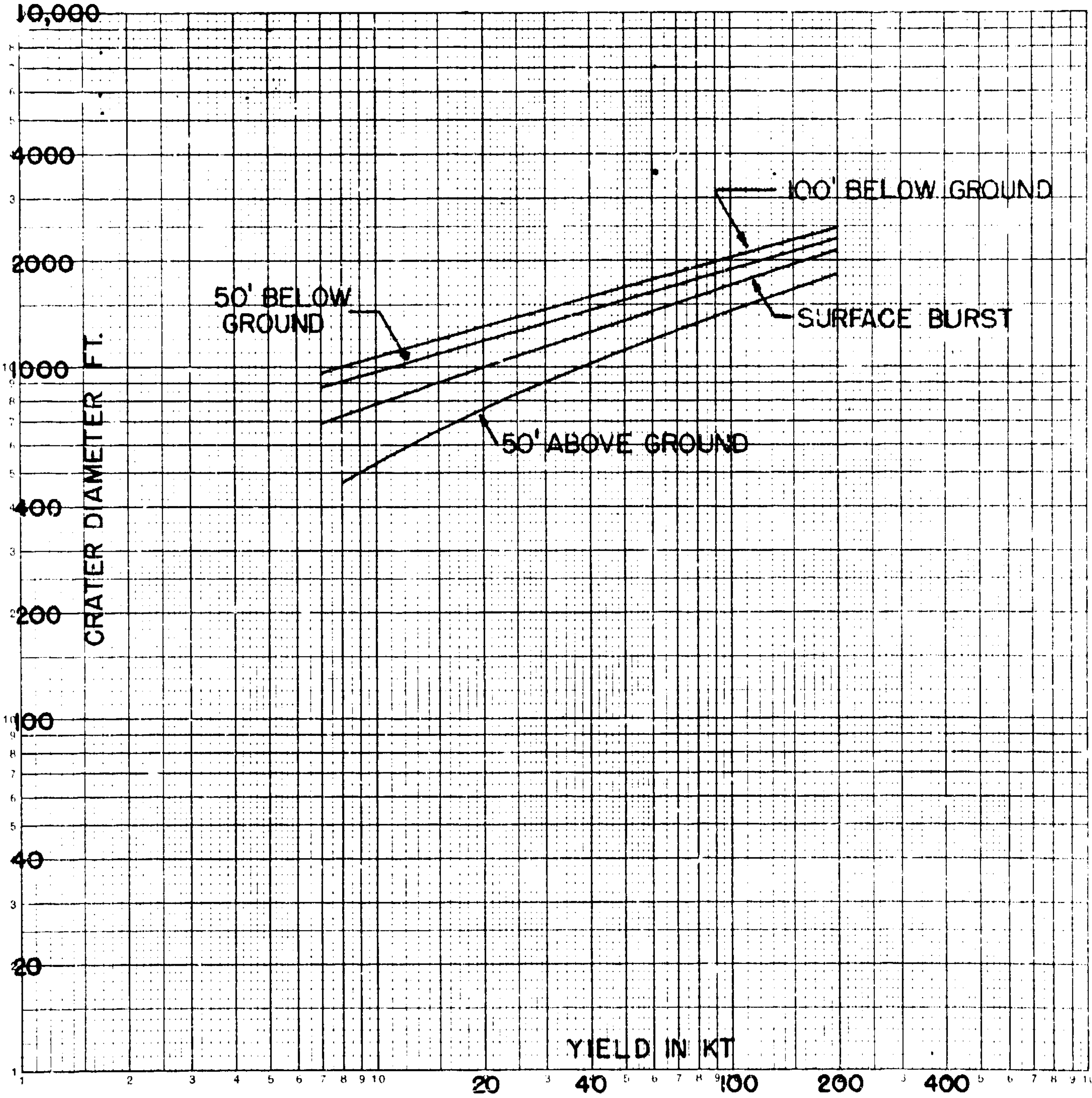
D_l = diameter of lip



$$h_l \simeq \frac{h_c}{4}$$

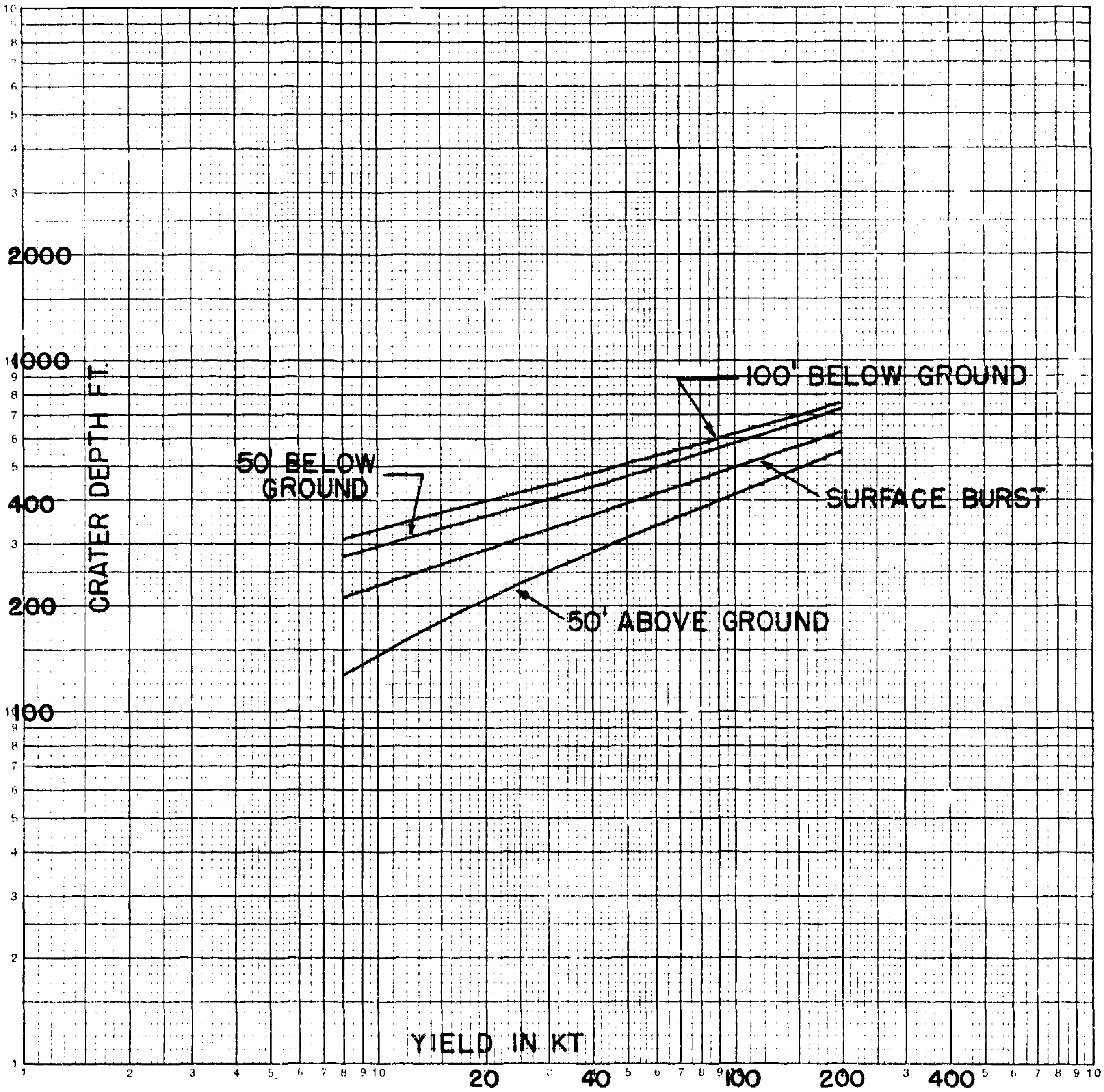
$$D_l \simeq 2 D_c$$

$$\text{Volume:} \quad V_c = \frac{1}{2} \pi \left(\frac{D_c}{2}\right)^2 h_c$$



Crater Diameters In Sand vs. KT Yield
for
Various Positions of Burst

FIGURE 3.4/a



Crater Depths in Sand
vs.
KT Yield
for
Various Positions of Burst

FIGURE 3.41b

3.42 Column and Base Surge :

a. Although only a small portion of the energy will be used for throw-out, consideration of the earth column is required because of missile and radiation contamination effects. From scaled HE data, it is expected that a nominal bomb burst in contact with the ground, or underground, will eject heavy missiles out to a considerable radius from ground zero. Missile damage to unshielded structures is to be expected.

b. Although the mass contribution to the finer ejected material (settle-out and drift-out) from the expelled earth is exceedingly small, practically all the radioactivity is expected to be concentrated in these fines. It is expected that a considerable proportion of the material will return to the earth within a range of a few miles. When the column falls back to the earth it is likely that a base surge will be formed such as was observed at Bikini Baker. (See Chapter VI). It will differ in that the particles will be solid, so that evaporation effects will be absent. The base surge will have dangerous ionizing radiation effects as discussed under "Nuclear Radiation", below.

3.5 Ground Shock

3.51 General :

The shape of a shock wave in any medium depends upon the relation between stress and strain in the medium and the boundary conditions. In earth, a shock wave does not have a vertical front as it does in air, but is characterized by a more gradual rise and decay in pressure as it passes any given point in the earth. Further, when measured near the

surface, it exhibits more than one cycle of rise and decay in pressure resulting in the familiar tremor felt during earthquakes. It is predicted that the period of these waves will vary from one-tenth of a second to several seconds.

3.52 Acceleration :

a. Maximum ground accelerations versus distance are shown on Figure 3.52a for 25 and 100 KT yield weapons detonated at four positions relative to the earth's surface (+50, 0, -50, -100). Note that the latter two positions of burst are for underground detonations (See Chapter V). These curves are plotted on the same figure for purposes of comparison.

b. In plotting these curves, a soil constant of 43,000 was used. This constant corresponds to a wet or saturated clay. Since accelerations in the earth vary directly with the soil constant, accelerations in any other soil may be computed by use of equation 3.1, and the soil constant of interest. (See Table I).

$$\frac{Ag_1}{k_1} = \frac{Ag_2}{k_2} \quad : \text{ at the same distance} \tag{3.1}$$

where:

Ag is the horizontal or vertical acceleration in units of gravity (384 inches/sec^2).

k is the soil constant.

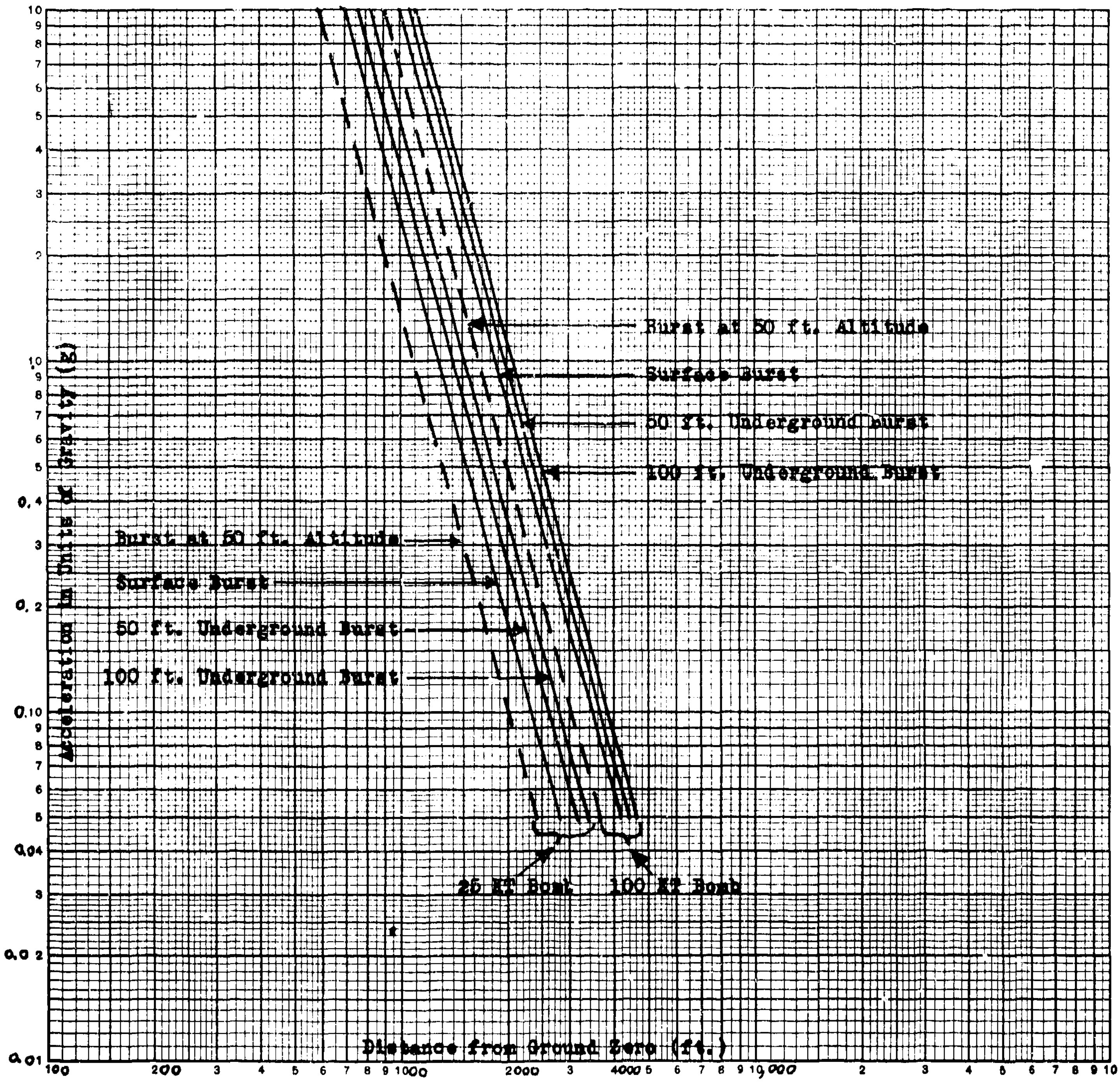


Fig. 3.52a. Free Earth Acceleration Vs. Distance from Ground Zero for 25 and 100 KT Bombs Burst at Various Positions Above and Below the Earth's Surface.

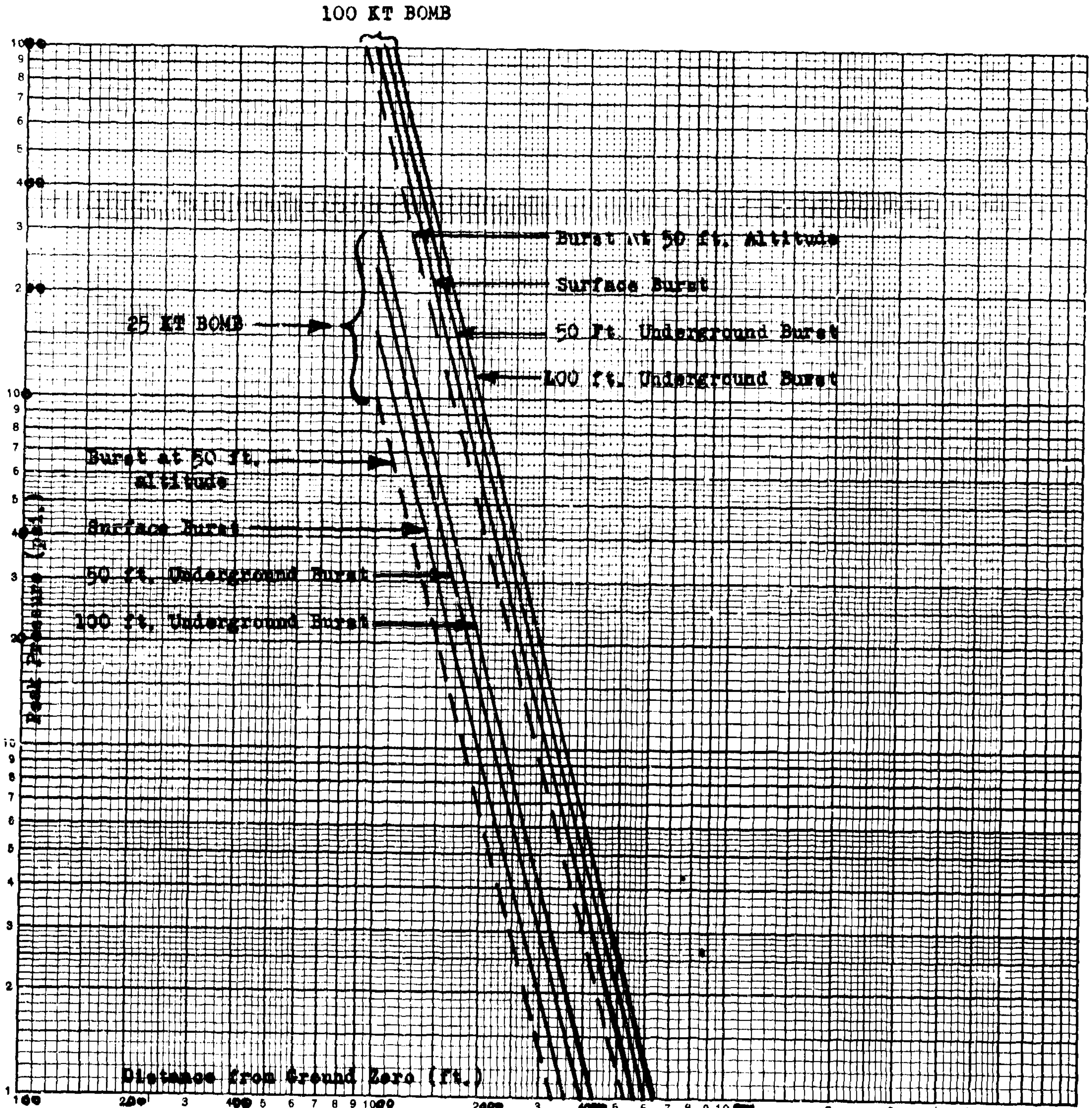


Fig. 3.53, Peak Pressure in Free Earth vs. Distance for 25 and 100 KT Bombs For Various Positions of Burst Above and Below Ground.

TABLE I

SOIL CONSTANTS AS A FUNCTION OF SOIL TYPE AND LOCATION

Soil Type	Location	k (min.)	k (max.)	k (ave.)
Loess - - - - - -	Natches, Miss - - - - -	400	1,700	800
Clay silt (loam)-	Princeton, N.J. - - - -	1,300	2,500	2,000
Silty clay- - - -	Camp Gruber, Texas- - -	1,300	9,000	5,100
Clay, unsaturated	Houston, Texas- - - - -	10,000	20,000	15,000
Clay, saturated -	Houston, Texas- - - - -	50,000	150,000	100,000

Example:

Given: The predicted ground acceleration at a range of 2,000 feet from the point of detonation of a 25 KT weapon burst at the surface in saturated clay (k = 43,000) is 0.17g.

Find: The acceleration predicted for the same range from the same weapon in loam (k = 2,000) (See Table I).

Solution:

$$Ag_1 = 0.17, \; k_1 = 43{,}000, \; k_2 = 2000$$

$$Ag_2 = 2000 \left(\frac{0.17}{43{,}000}\right)$$

$$\frac{0.17}{43{,}000} \times 2{,}000 = \underline{\underline{0.0059.}} \quad \text{ans}$$

3.53 Peak Pressure

Figure 3.53 shows the variation in peak pressure with distance for 25 KT and 100 KT yield bombs, detonated at 50, 0, -50, and -100 feet,

These curves are also based on a soil constant of 43,000 (a saturated clay). Like acceleration, peak pressure varies directly with the soil constant. To determine the predicted peak pressure in other soils, use equation 3.2 below:

$$\frac{P_1}{k_1} = \frac{P_2}{k_2} \qquad (3.2)$$

: at the same distance

where: p = peak pressure in psi

k = soil constant

3.54 Impulse :

Similarly, Figure 3.54 shows the variation in impulse with distance. However, impulse at any distance varies with the square root of the soil constant. To determine predicted impulse in any soil other than saturated clay, use equation 3.3 below:

$$\frac{I_1}{(k_1)^{1/2}} = \frac{I_2}{(k_2)^{1/2}} \qquad (3.3)$$

: at the same distance (from same yield bomb).

where: I = impulse in lb. sec. per in^2

k = soil constant

3.55 Displacement :

Curves for maximum transient displacement versus distance from 25 KT and 100 KT bombs, detonated at the same four positions are given in Figure 3.55. As before, the displacements shown have been computed for a saturated clay (k = 43,000). Maximum transient

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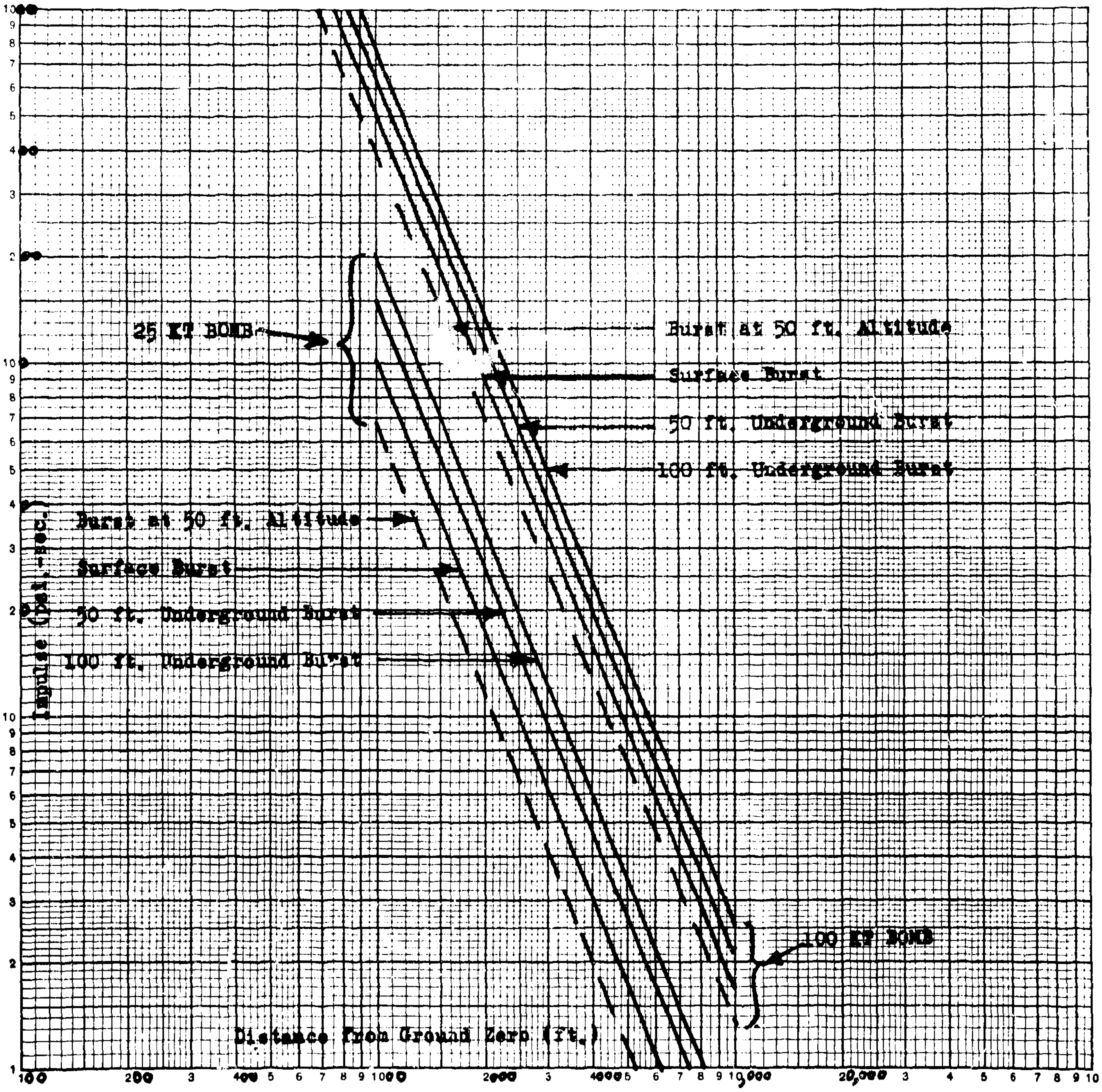

Fig. 3.54. Impulse in Free Earth vs. Distance for 25 KT and 100 KT Bombs Burst at Various Positions Above and Below the Earth's Surface.

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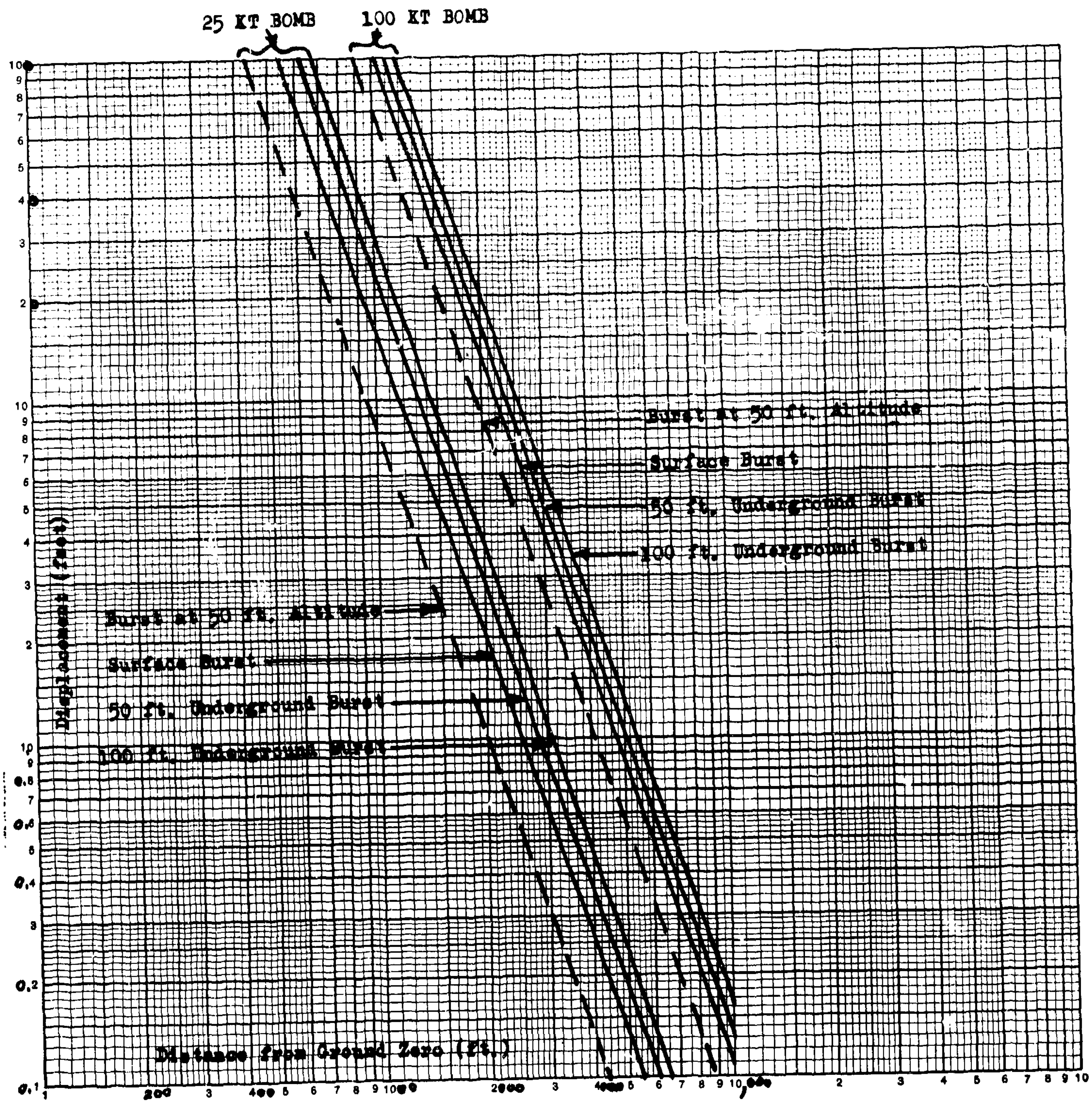

Fig. 3.55. Maximum Transient Displacement vs. Distance from Ground Zero for 25 and 100 KT Bombs Burst at Various Positions Above and Below the Earth's Surface.

displacement varies with cube root of the soil constant. Use equation 3.4 to determine these displacements in other soils.

$$\frac{D_1}{(k_1)^{1/3}} = \frac{D_2}{(k_2)^{1/3}} \quad \text{: at the same distance} \tag{3.4}$$

where: D = maximum transient displacement in feet

k = soil constant

Permanent displacements should be approximately one-third the transient displacements obtained from the curve above.

3.56 Energy Ratio:

a. Energy Ratio (E. R.) is a useful tool in predicting damage to structures. The E. R. may be expressed in terms of acceleration and displacement as follows, if a sinusoidal wave form is assumed.

$$E.R. = 4\pi^2 a D \tag{3.5}$$

where: a is acceleration in ft/sec

D is ground displacement

E. R. is Energy Ratio in ft/sec^2

b. Equation 3.5 was used, in conjunction with Figures 3.52a and 3.55, to compute Figures 3.56a and 3.56b, which show E. R. as a function of distance for 25 KT and 100 KT yield weapons detonated at +50, 0, -50, and -100 feet in two kinds of soil.

3.57 Surface Waves :

In an underground explosion, surface waves are formed. In normal explosions these waves cause no significant damage. In an

explosion of the magnitude of a 20 KT bomb or greater, they may cause damage at greater distances from the explosion, than the direct wave. However, damage due to these surface waves is not taken into account in this handbook at this time.

3.6 Thermal Radiation

3.61 When an atomic weapon is exploded on the surface of the e arth, the fireball will transfer approximately one-half of its thermal energy to the surface. This transfer will be accompanied by considerable dust clouds whose density will depend on the particular soil condition, height of burst, and bomb yield. The fireball will behave in exactly the same manner as the air burst weapon except it will contain less thermal energy than the same yield in an air burst weapon.

3.62 It is possible and convenient for thermal pusposes only to consider a "Thermal Equivalent Air Burst Yield". This "Equivalent" is an air burst yield of sufficient magnitude to give the same thermal results as the surface weapon. When all factors are considered, it is estimated that a surface detonation will radiate 1/3 as much thermal energy as will an air burst of the same yield. Therefore, to get the "Thermal Equivalent Air Burst Yield" of a surface burst, it is necessary only to divide the total surface yield by three and then examine the effects from an air burst weapon of this yield. The thermal energy received from a surface burst, as a function of distance, yield, and atmospheric attenuation, utilizing the "Thermal Equivalent Air Burst Yield", is thus given by Figures 2.43b(1) through 2.43b(9).

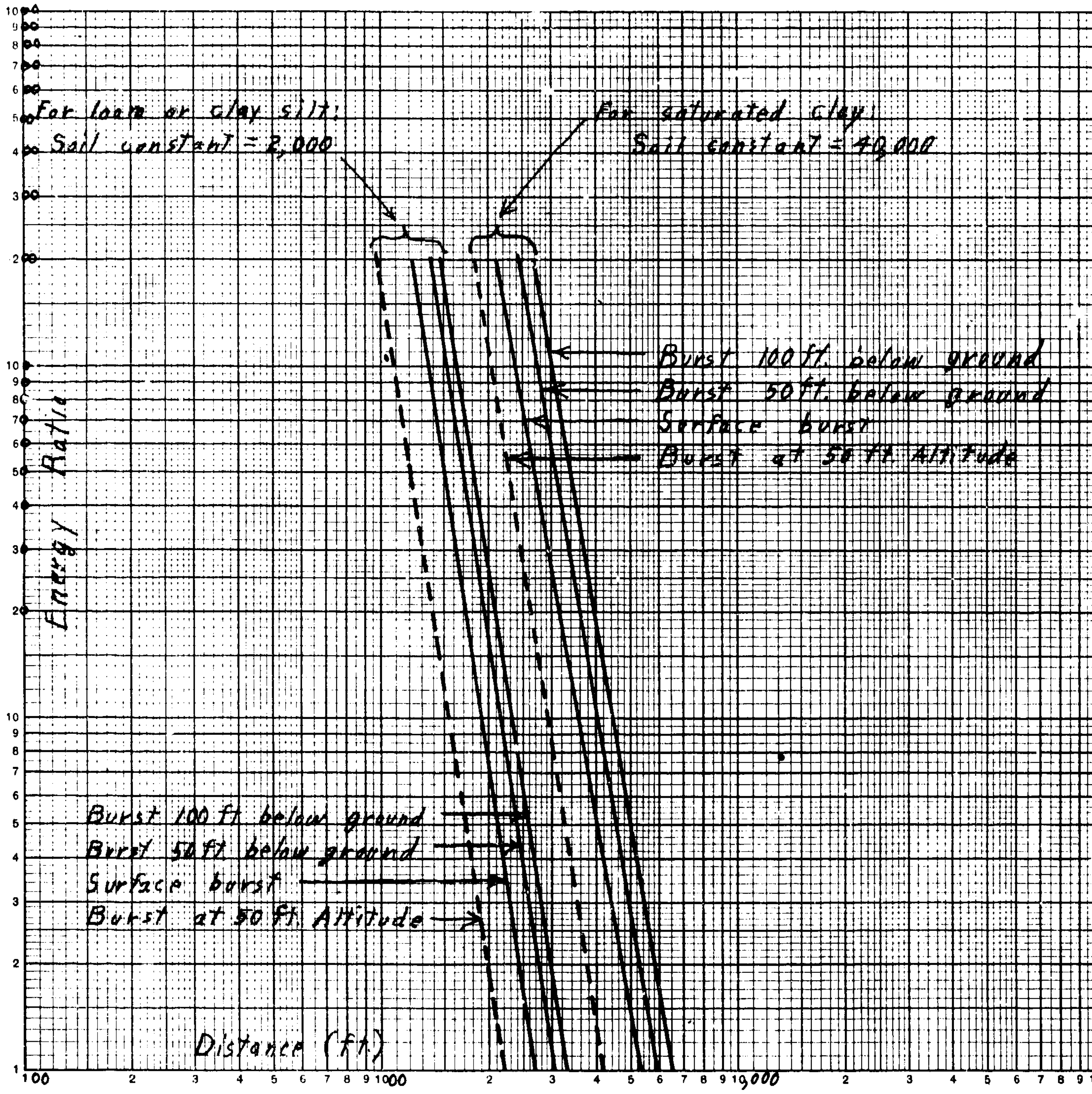

Figure 3.56a Energy ratio versus distance from burst for 25 Kt. detonation at various positions above and below the earth's surface for two types of soil.

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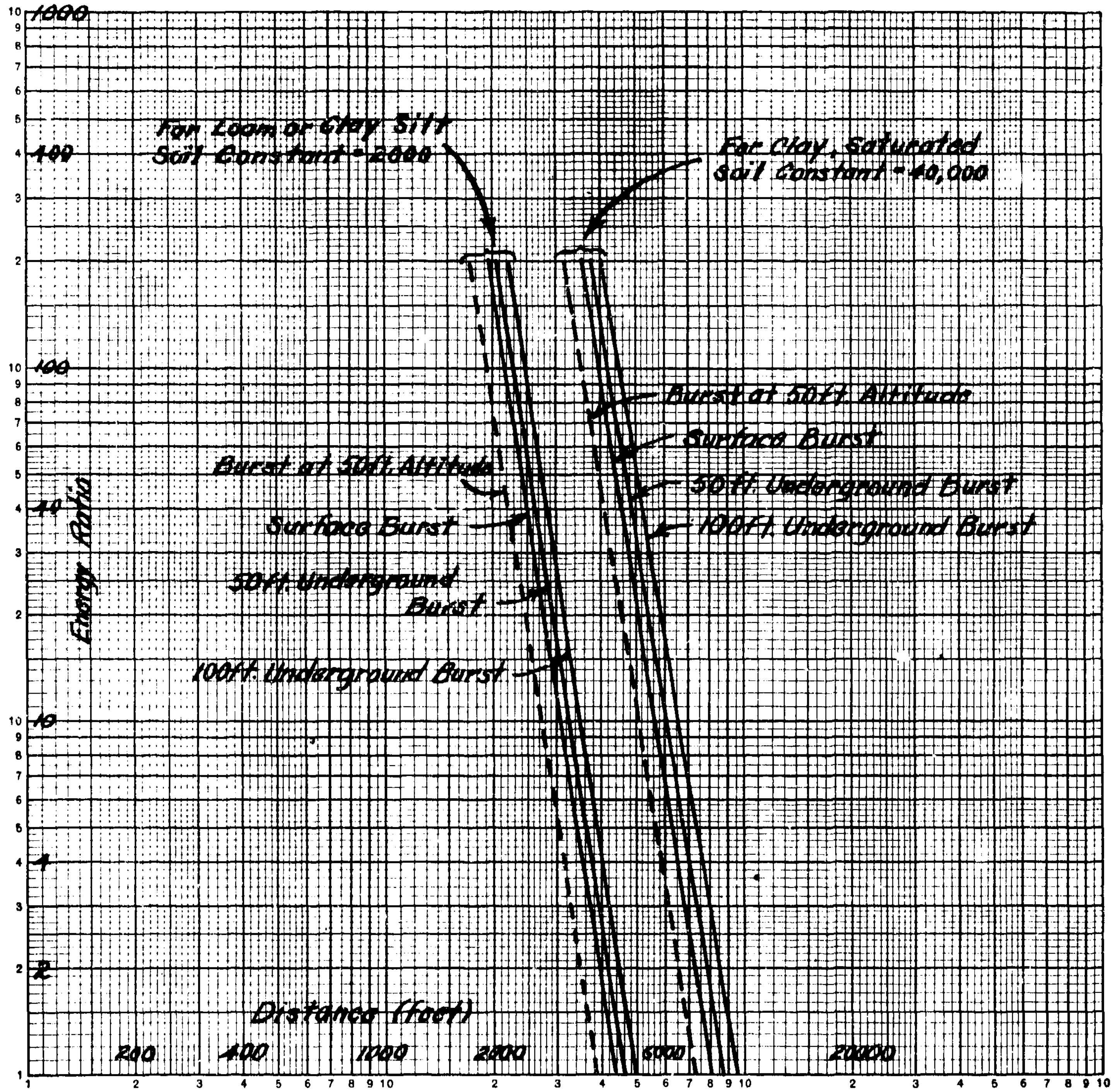

Figure 3.56b Energy Ratio vs. Distance for 100 KT Burst at Various Positions Above and Below Earth's Surface for Two Types of Soil

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Example:

Given: A 60 KT yield bomb is detonated at the surface of the earth.

Find: The "Thermal Equivalent Air Burst Yield"

Solution:

60/3 = 20 KT <u>ans</u>

Therefore, use the 20KT air burst curves for the proper atmospheric conditions. (See Chapter II).

3.7 <u>Nuclear Radiation</u>

3.71 Initial Radiation :

The initial radiations from a surface detonation of an atomic bomb should be quite similar to those from an air burst (See Chapter II), since any earth or water thrown up by the force of the explosion will be thrown up too late to absorb an appreciable fraction of the radiation.

3.72 Residual Radiation :

a. The residual radiation from a surface detonation will be considerably greater than from an air burst because of possible local fall-out from the cloud and base surge and from direct contamination of the crater and lip. The extent of this contamination cannot be accurately predicted at the present time and will always be somewhat dependent on the exact character of the soil and atmospheric conditions at the time of the detonation. In a calm the contamination will be symmetrical around the point of detonation and relatively more dense. As the wind increases the pattern will be elongated and displaced

in a downwind direction and the contamination less dense.

b. An estimate of the dose rate as a function of distance at one hour after the detonation for a 20 KT burst in a 5mph wind is shown in Figure 3.72b. The dose rates will be approximately proportional to the size of the explosion so that, for example, the dose rate for a 100 KT explosion will be about five times that for a 20 KT shot. It should be emphasized, however, that the values in Figure 3.72b are essentially average values and that there may be considerable local variations.

c. In order to calculate the dose rate at other times after the detonation, the decay curve shown in Figure 3.72c may be used. Use care in applying this decay curve. Remember that it does not specify the dose rate at any given point at any time; it only shows the rate of decay. To use the decay curve, it is necessary to know what the dose rate is at a given point at a given time after detonation.

Example:

Given: The dose rate at a given point at one hour after detonation is 500 r/hr.

Find: The dose rate at that point 6 hrs after detonation.

Solution:

From Figure 3.72c 1 r/hr at one hour after detonation would have decayed to 0.11 r/hr at 6 hours after detonation.

$$\frac{X}{500} = \frac{0.11}{1}$$

$$X = 500(0.11) = 55\ r/hr$$ ans

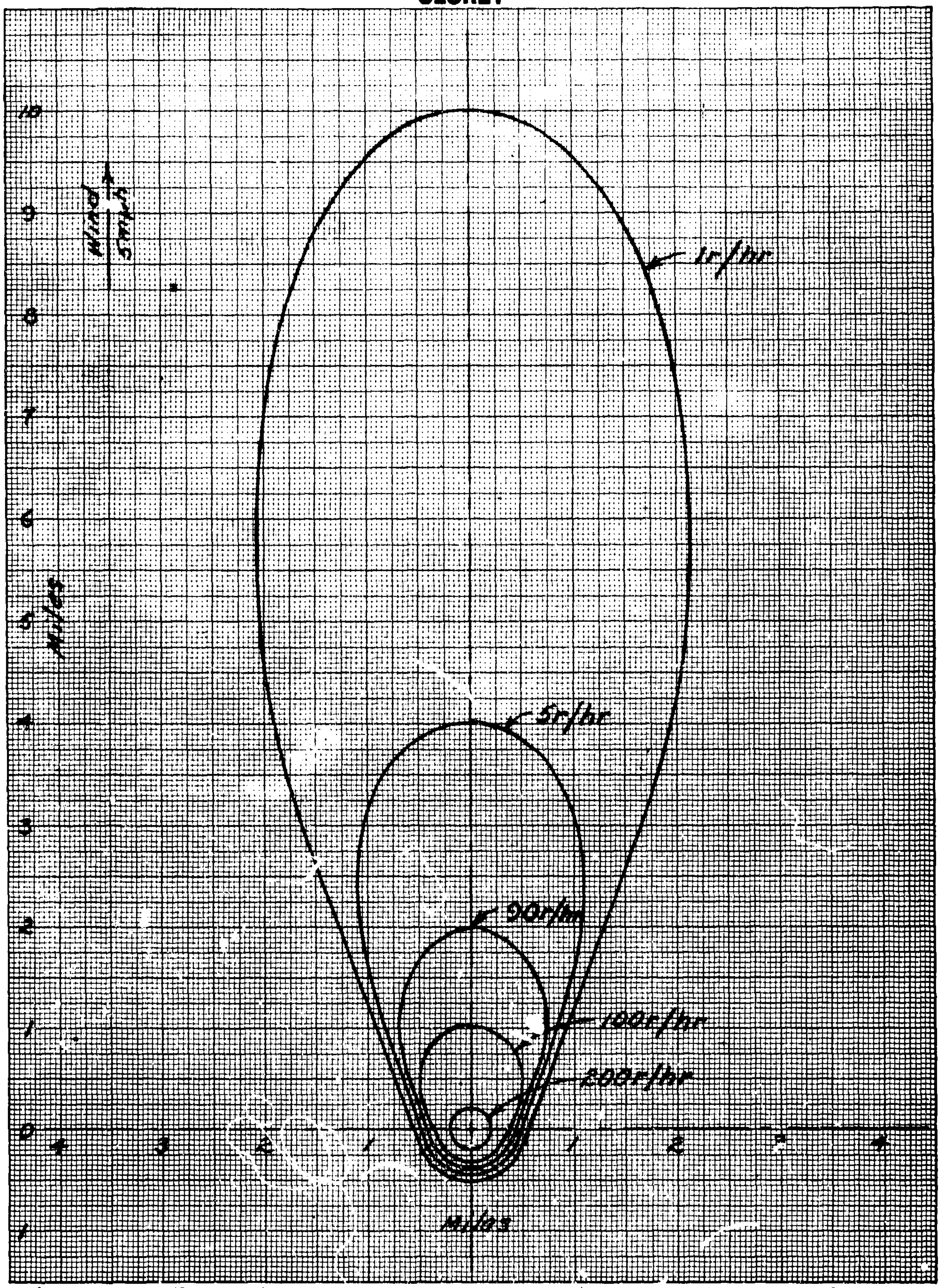

Figure 3.72b Radiation Dosage Rate Contours at 1 Hour after Explosion of Surface Burst (20KT)

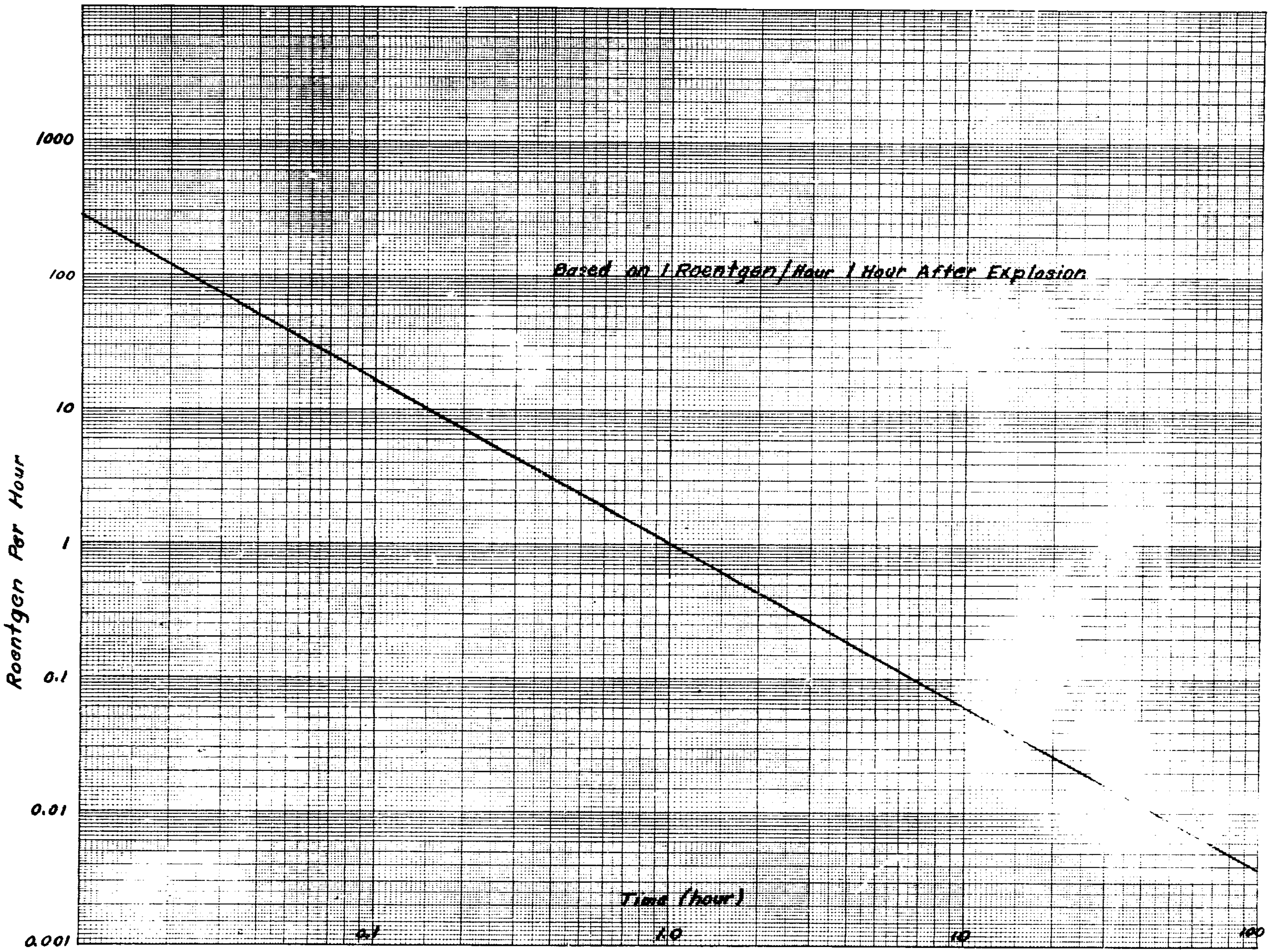

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Figure ~~10~~. Dosage Rate as Function of Time

The decay curve may also be used to determine what the dose rate at a given point was at a time previous to the time after detonation at which it is measured.

Example:

Given: The dose rate at a given point 6 hours after detonation is 55 r/hr.

Find: The dose rate at that point 1 hour after detonation.

Solution:

From Figure 3.72c, the dose rate at 6 hours after detonation is 0.11 r/hr and the dose rate at 1 hour after detonation is 1 r/hr

$$\frac{x}{55} = \frac{1}{0.11}$$

$$x = \frac{55}{0.11} = \underline{\underline{500}}\ r/hr \quad \underline{\text{ans}}$$

d. Figure 3.72d shows the total dosage a man would receive if he entered a contaminated area at a specified time after the explosion and remained for a given length of time. Here, it is necessary to know the dose rate in a given area at 1 hour after detonation before this curve can be used.

Example:

Given: The dose rate in a given area at 1 hour after detonation is 500 r/hr

Find: The total dosage received by a man entering the area two hours after detonation and

remaining for three hours.

Solution:

From Figure 3.72d the intersection of the line for a time of entry of two hours after detonation and the three hour curve occurs opposite 0.7 on the ordinate (vertical axis). Since the ordinate is expressed in terms of total dosage divided by the dose rate at 1 hour after detonation;

$$\frac{\text{Total Dosage}}{500} = 0.7$$

Total Dosage = 350 r. ans

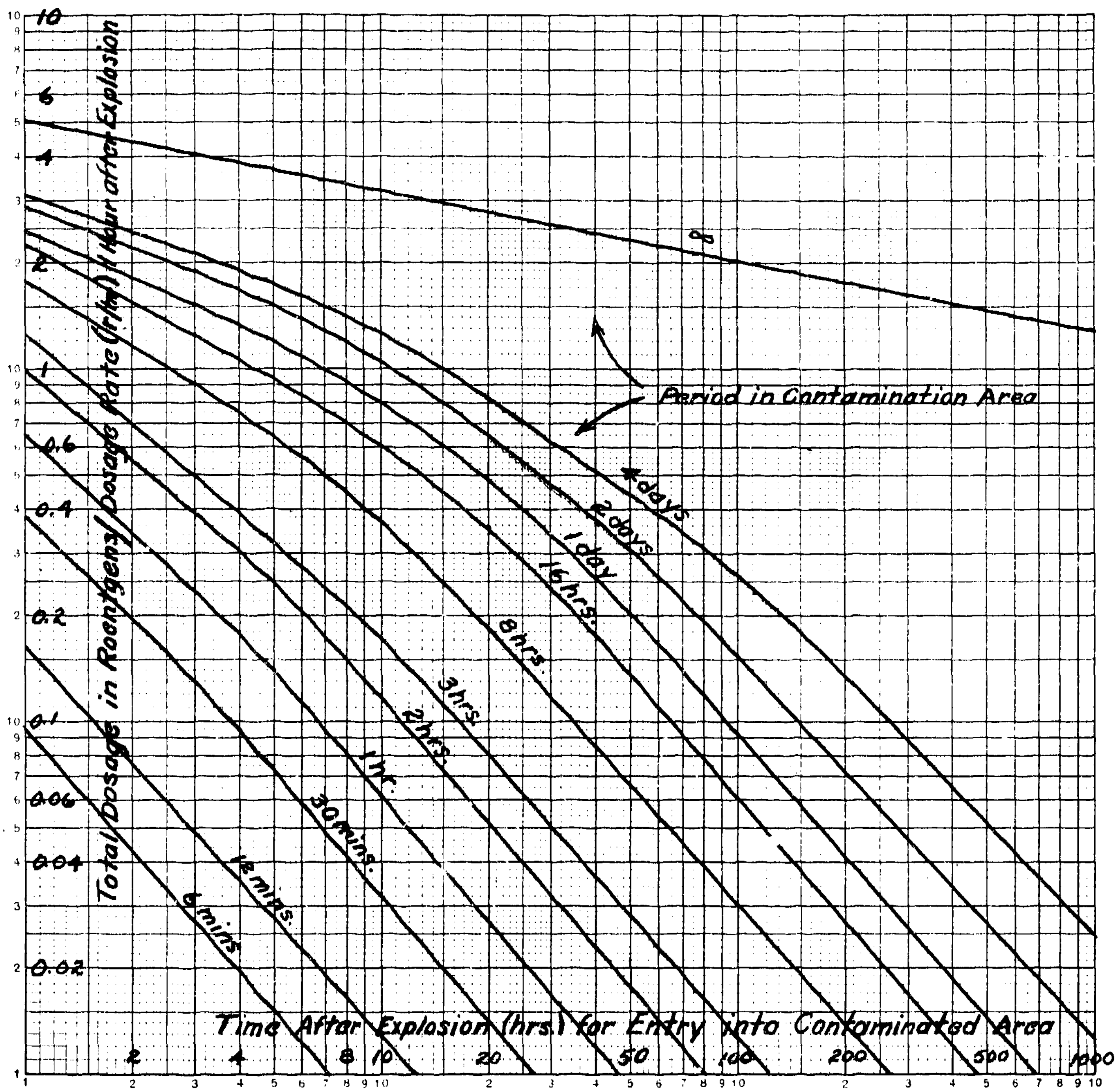

Figure 3.72d Total Radiation Dosages in a Contaminated Area

CHAPTER IV

THE SURFACE BURST : WATER

4.1 Brief Description of Surface Burst (Water)

Although the initial stages of a surface burst of an atomic weapon over water should be similar to those over land, there are certain obvious differences in the various physical effects. Very little is known about this type of burst. However, a qualitative presentation can be made. In general, the effects of this type of burst bear some resemblence to both the surface burst over land and to the underwater burst.

4.2 Energy Distribution

Following is an estimated partition of energy for the surface burst over water:

Air Blast		35%
Column and Waves		10%
Water Shock		15%
Vaporization & Thermal Radiation		25%
Vaporization	15%	
Thermal Radiation	10%	
Nuclear Radiation		15%
Instantaneous Gammas	5%	
Residual Contamination	10%	

4.3 Air Blast

It is predicted that there will be no significant difference in the air blast overpressures at any distance from those obtained from a surface burst over land. See Chapter III for a discussion of this subject.

4.4 Column and Waves

4.41 Column and Base Surge :

The column of water resulting from a surface detonation over water should be of lesser magnitude than that obtained from an underwater detonation. (See Chapter VI). However, it is predicted that a base surge will be formed when the column of water falls back to the surface.

4.42 Waves :

a. From relatively small scale experiments with TNT, it is predicted that a true surface detonation will produce higher surface waves than any other position of detonation for the same yield bomb. The relation between the wave height (from crest to following trough), horizontal range and yield is expressed as follows:

$$HR = K W^{1/2} \tag{4.1}$$

where: H is the gross wave height from crest to trough in feet.

R is range in feet.

K is a constant dependant upon the position of detonation.

W is equivalent TNT yield in pounds.

b. This equation applies only to detonations in or at the surface of the water of such a depth that the bottom is not exposed by the detonation. For a detonation at the surface, K = 30 (a conservative approximation). Further, equation (4.1) must be modified to include the effect of boundary conditions, such as bottom slope and channeling. These will be discussed later.

Example:

Given: A 20 KT weapon is detonated at the surface in deep water.

Find: The gross wave height at 5,000 feet from the point of detonation.

Solution: $HR = KW^{1/2} = 30(40,000,000)^{1/2}$

$$HR = 30(6300) = 189,000$$

$$H = \frac{189,000}{5000}$$

$$H = \underline{38} \text{ ft}$$ ans

c. The number of waves experienced varies with the range or horizontal distance from the point of detonation. A relation between the number of effective waves in the group and the range has been found to be:

$$N = 2 + R/\lambda \qquad (4.2)$$

where: N is the number of waves in the group of greater amplitude than one-fifth of the maximum wave height.

λ is the wave length from crest to crest in feet.

R is the range or horizontal distance from explosion in feet.

d. In the preceding equation the number of waves in the group is expressed as a functtion of the wave length. The wave length has been determined to be approximately:

$$\lambda = K' W^{1/4} \tag{4.3}$$

where: λ is the wave length from crest to crest in feet.

$K' = 11$; is an emperical constant.

W is the equivalent TNT yield in pounds.

Example:

Given: A 20 KT weapon is detonated at the surface in deep water.

Find: The number of waves produced at a range of 500 feet.

Solution: $\lambda = K' W^{1/4} = 11\,(40 \times 10^6)^{1/4}$

$\lambda = 11\,(80) = 880 \text{ ft}$

$N = 2 + 5000/880$

$N = \underline{\underline{7 \text{ or } 8}}$ waves

ans

e. The velocity at which the individual waves are propagated is a function of the wave length:

$$V = 2.26\,(\lambda)^{1/2} \tag{4.4}$$

where: V is velocity in feet per second.

λ is wave length from crest to crest in feet.

From equation 4.4 the time of arrival of the surface waves can be computed by dividing the horizontal distance from the explosion by the velocity obtained as above.

Example:

Given: A 20 KT weapon is detonated at the surface in deep water.

Find: The time of arrival of the first wave at a ship 5.000 feet from the point of detonation.

Solution: From the problem in d above λ = 880 feet.

$$V = 2.26\,(880)^{1/2}$$

$$V = 2.26\ (30) = 67.5 \text{ feet per second}$$

$$t = 5000/67.5 = \underline{74 \text{ seconds}}. \quad \underline{\text{ans}}$$

g. The previous discussion has been concerned with waves generated and traveling in deep water. The formation of waves caused by explosions in shallow water is not yet understood completely. However, the effect of bottom slope and channel restrictions on the height of existing waves is known. A gradual decrease in depth of water and width of channel will cause an increase in the height of the surface wave until the breaker height is attained.

4.5 Water Shock

No quantitative information is available on this subject. It can be predicted qualitatively that energy to water shock from a near surface burst will be approximately one-half of that from a burst at

90 feet beneath the water (Bikini Baker), of the same yield weapon.

4.6 Vaporization and Thermal Radiation

No significant difference is predicted between the thermal radiation effect of a surface burst over land and surface burst over water. See Chapter II for a discussion of thermal radiation from a surface burst.

4.7 Nuclear Radiation

Instantaneous nuclear radiation intensities, at any distance should be essentially the same for a surface burst over water and a surface burst over land. There will be a significant difference in the character and distribution of residual contamination between the two types of surface detonations. In this respect the surface water burst should resemble closely the underwater burst, though the dose rate of the residual contamination should be less (perhaps by a factor of 3). Therefore, the total dosage would be correspondingly reduced. See Chapter V for a discussion of residual contamination resulting from an underwater burst.

CHAPTER V

THE UNDERGROUND BURST

5.1 Brief Description

5.11 When an atomic weapon is burst underground (depth of burst 50 feet or greater) a ball of fire will be formed which will be made up of vaporized materials from the bomb, vaporized earth and other hot gases. The light which has been observed in air bursts will not be visible before the surface of the ground has ruptured and will probably be obscured by dust and vapor clouds after rupture.

5.12 The first physical effect of the explosion to be observed will probably be a dome shaped upheaval of earth of considerable radius directly above the point of detonation. Then the gas bubble will begin to vent near the center of the dome. As these gasses are released, they will carry a large quantity of earth high into the air in the form of a cylindrically shaped column similar to that observed in the underwater test at Bikini, though of lesser diameter. It is estimated that this column will reach a height of approximately 8,000 feet and a diameter of 1,200 feet for a 20 KT burst at 50 feet depth.

5.2 Energy Distribution

The partition of energy for an atomic explosion occurring 50 feet underground has been estimated as follows:

Air Blast	20%

Cratering and Column			15%
Ground Shock			25%
Fuzing and Vaporization			25%
Nuclear Radiation			15%
	Instantaneous Gammas and Neutrons	5%	
	Residual Contamination	10%	

5.3 Air Blast

Figure 5.3 shows peak air overpesssure versus distance for various KT bombs at charge depths of 50 - 100 feet. For discussion of air shock see Chapter II.

5.4 Cratering and Column

See Chapter III for discussion of cratering and column. Figures 3.41a and 3.41b show crater dimensions versus yield for underground detonations at 50 and 100 feet below the surface.

5.5 Ground Shock

See Chapter III for discussion of ground shock and explanations of the use of Figures 3.52 to 3.55 showing acceleration, peak pressure, impulse, and displacement versus distance, for 25 KT and 100 KT weapons at 50 and 100 feet below the earth's surface. It is pointed out that in computing these data for both surface and underground bursts, it was assumed that the scaling laws are valid.

5.6 Thermal Radiation

Because the bomb is burst underground and because the fireball will be obscured by the earth column after rupture, thermal radiation

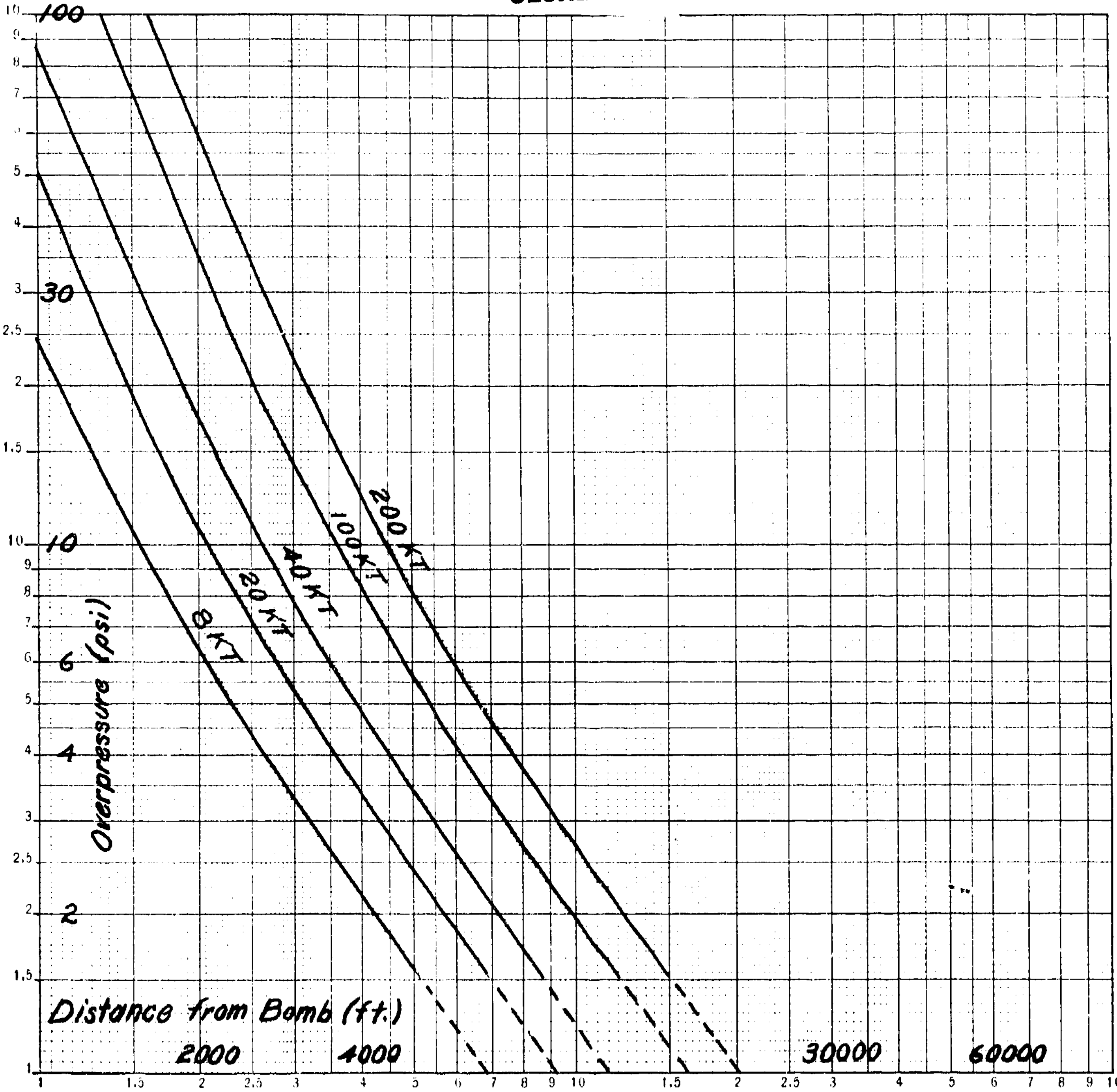

Figure 5.3 Airblast Overpressure on Ground vs. Distance From Bomb for Various KT Yields (Bomb Burst at 50'-100' Depth Below Earth's Surface, Land or Water)

effects are predicted to be negligible. Nearly all of the thermal radiation will be absorbed in fuzing and vaporizing the earth.

5.7 Nuclear Radiation

5.71 Initial Radiation :

If an atomic bomb is detonated at an appreciable depth beneath the surface (greater than 20 feet), it is anticipated that the initial gamma and neutron radiations will be absorbed to such a large extent by the surrounding material that they will be of negligible importance at any distance from the point of detonation.

5.72 Residual Radiation :

It is anticipated that the residual radiation from an underground burst will be extremely high because of heavy fall-out to radioactive material from the cloud and base surge. This residual radiation will result primarily from the active material actually deposited on the surface, but, in addition, there will be a small contribution from the radiation from the active material as it is carried along by the cloud and base surge. The total gamma radiation dosage as a function of distance for a 20 KT underground burst is given in Figure 5.72a. The largest fraction of this dosage (greater than 50%), will, in general, be obtained during the first 30 minutes after the detonation. The dose rate as a function of distance at one hour after the detonation is given in Figure 5.72b. In order to calculate the dose rate at any other time after the detonation, the decay curve in Figure 3.72c can be used. The dosage received by personnel entering the contaminated areas after the detonation can be calculated using Figure3.72d in the

same manner as with the surface burst. (See Chapter III). The dosages and dose rates for bombs of other yields than 20 KT will be approximately proportional to the ratio $\frac{w}{20}$.

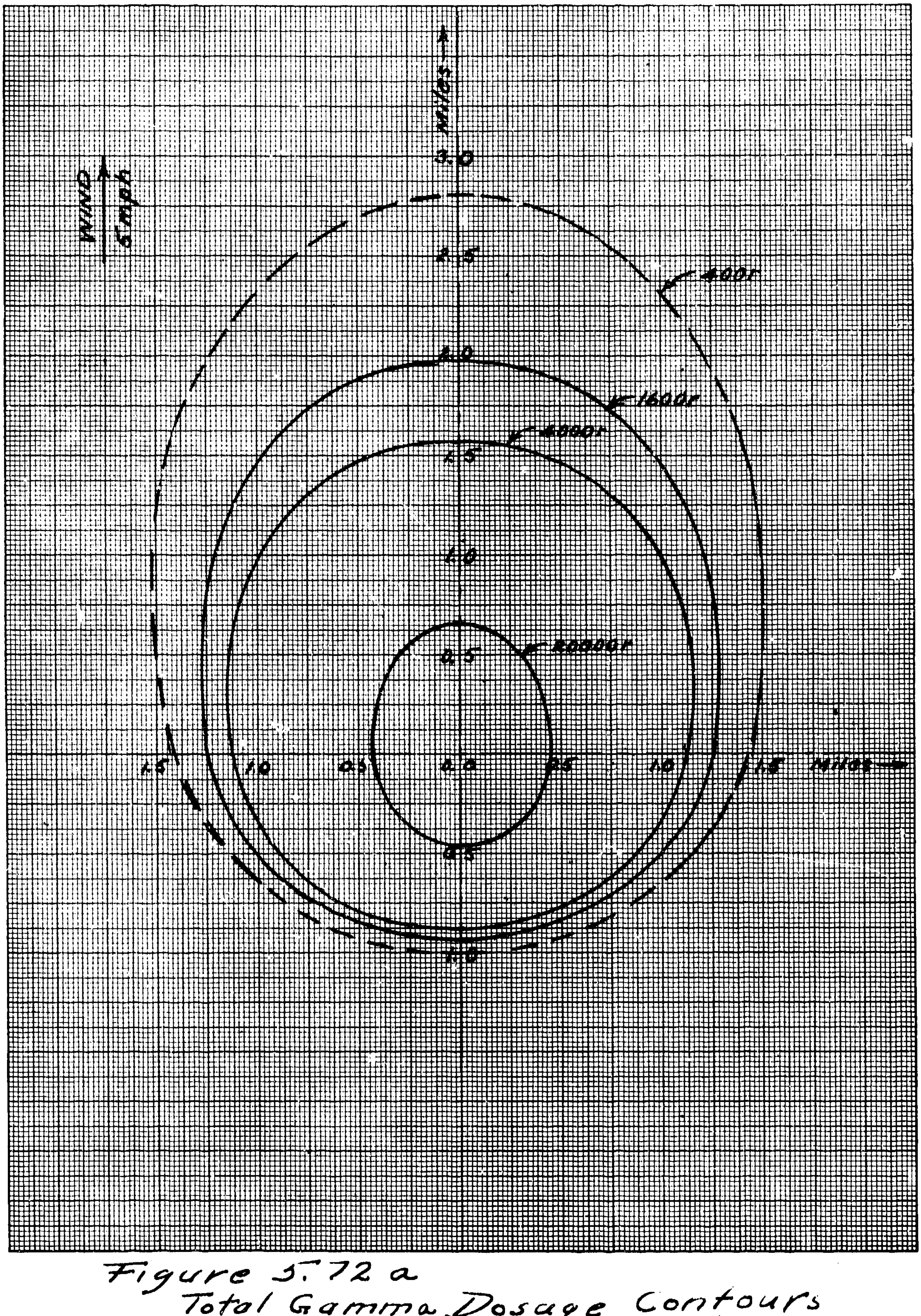

Figure 5.72 a
Total Gamma Dosage Contours
(20 KT Underground)

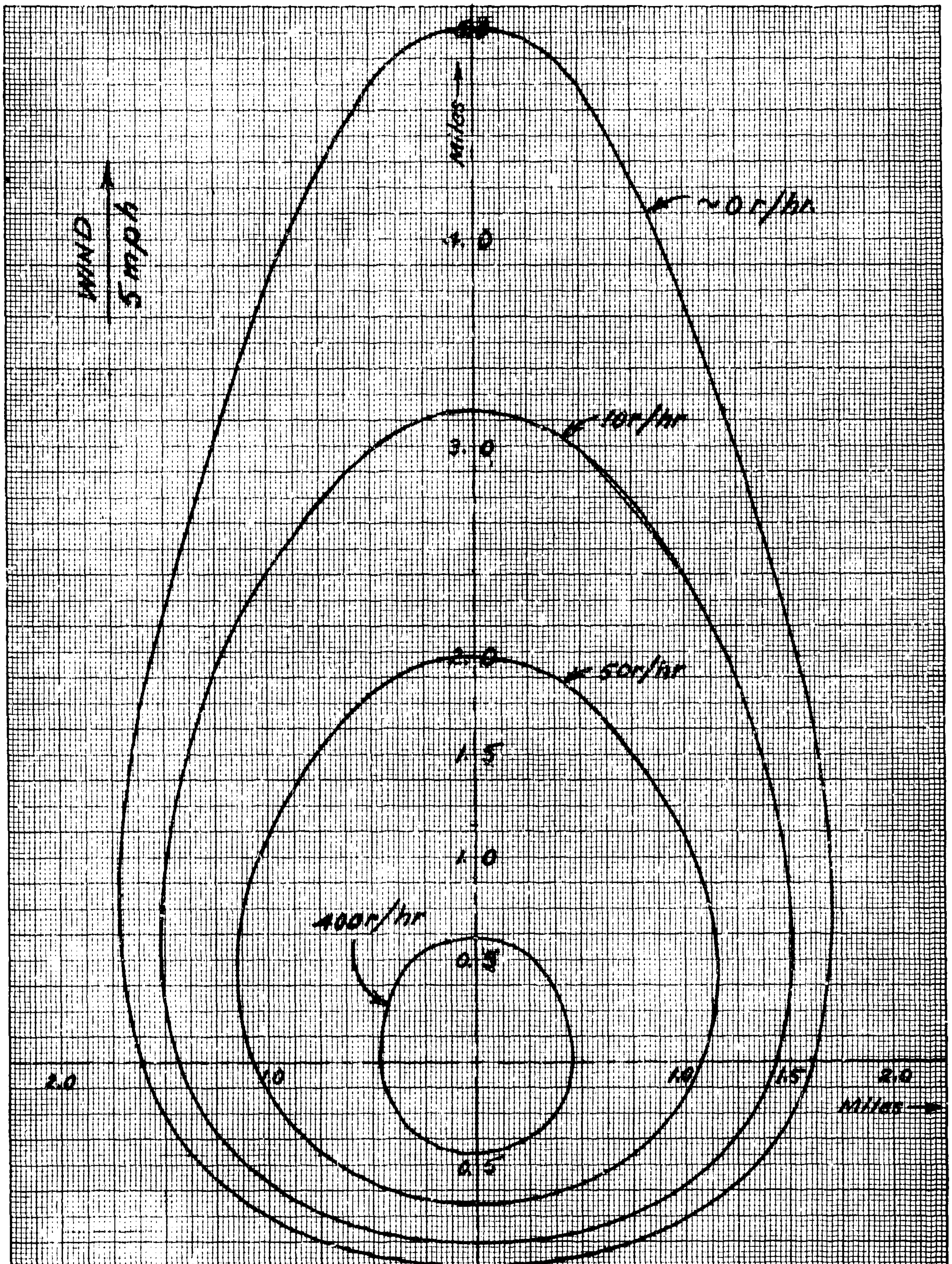

Figure ~~17~~ 5.72b Radiation Dosage Rate Contours at 1 Hour after Explosion of an Underground Burst (20 KT)

CHAPTER VI

THE UNDERWATER BURST

6.1 Brief Description

6.11 When an atomic weapon is detonated underwater the phenomena observed differ from those described for the other types of burst. As in all previous cases, a ball of fire is formed. Observers of the "Baker" test at Bikini saw the water, in the vicinity of the explosion, lighted up, though distortion due to waves prevented a clear veiw of the fireball. The luminosity remained for a few milliseconds, but disappeared as soon as the bubble of hot gases constituting the ball of fire reached the water surface and cooled upon expansion.

6.12 As in the case of the underground detonation, a shock wave is formed in the water by the initial rapid expansion of the fireball. A shock wave is formed in the air, subsequently, by the rapid rise of the water column and the expansion of the gas bubble in the atmosphere. Under the proper atmospheric conditions, (relative humidity greater than 60%) a Wilson cloud may be formed as described in Chapter II.

6.13 The height to which the column of water will rise is dependent upon the energy of the explosion, the depth of water, and the depth of detonation. As the column falls back into the water, a wave or cloud of mist is formed around the base of the column. This highly radioactive cloud of mist, called the base surge, is an important effect of the underwater burst and will be discussed more fully below.

6.2 Energy Distribution

The partition of energy, from a nominal atomic bomb, for a shallow underwater explosion (50 - 100 feet below the surface) has been estimated as follows:

Air Blast		25%
Column, Base Surge, Waves and Cratering		10%
Water Shock		30%
Vaporization		20%
Nuclear Radiation		15%
Instantaneous Gammas and Neutrons	5%	
Residual Contamination	10%	

6.3 Air Blast

See Figure 5.5, Chapter V, for curve showing air blast overpressures versus distance for various KT bombs detonated 50-100 feet underwater. These overpressures will be essentially the same as those from the underground burst.

6.4 Column and Base Surge

6.41 At Bikini (Test Baker) where a 20 KT bomb was detonated at a depth of 90 feet in 180 feet of water a conical spray dome began to form at about four milliseconds after the explosion. Its initial rate of rise was greater than 2,500 feet per second. A few milliseconds later the hollow column began to form, rapidly overtaking the spray-dome. The maximum height obtained by the column of water was probably some 8,000 feet, and the greatest diameter was about 2,000 feet. The

maximum thickness of the walls of the column was about 300 feet, and approximately one million tons of water were thrown into the air.

6.42 As previously explained, what is known as a base surge is formed as the column of water falls back to the water surface. At Bikini, the base surge began to form within 10 seconds after the bomb was detonated and moved rapidly outward at an initial velocity of greater than 100 feet per second. In the first hundred seconds, the average velocity was 63 feet per second. In 160 seconds the surge had travelled 7,800 feet. Figure 6.42 gives the radius of the base surge at any time for four bombs; 20 KT, 40 KT, 100 KT and 200 KT, where depth of water, and depth of detonation are scaled to Bikini Baker in accordance with the cube root law.

6.43 The maximum and minimum depths at which the bomb must be burst for the production of a base surge have not been determined exactly. However, it is estimated that a nominal bomb burst at 500 feet should produce a base surge and model experiments have indicated that a base surge is obtained when the nominal bomb is detonated at a depth of 30 feet. It has been determined that the size of the base surge is a function of the column diameter. Therefore, a base surge is predicted for any position of detonation which forms the water column.

6.5 Waves

6.51 The underwater burst at Bikini was in effect a shallow water detonation. For that reason the equations presented in Chapter IV do not apply without modification. Table II lists maximum heights of waves obtained at various distances from the epicenter of the explosion

at Bikini Baker.

TABLE II

R, Distance (thousands of feet)	1	2	4	6	8	10	12
H, Maximum Height (feet)	94	47	24	16	13	11	9

H = maximum height in feet from crest to following trough.

R = distance from the explosion in feet.

6.52 Two empirical equations may be used to determine wave heights at any horizontal distance from the shallow underwater explosion at Bikini. Within 8,000 feet, where the first wave is the highest wave, the relationship $HR = 94\cancel{,000}$ can be used to estimate maximum wave height at any given distance. Beyond 8,000 feet, the empirical $(HR)^{0.9} = 42{,}700$ should be employed.

6.53 In Table III values are given for the times of arrival of the first crest at different distances from the underwater explosion at Bikini. The time interval between the first and the second wave crests was less than 20 seconds at 2,000 feet and increased to 40 seconds at 12,000 feet.

TABLE III

Distance (thousands feet)	1	2	4	6	8	10	12
Arrival time (seconds)	11	23	48	74	101	127	154

6.54 The size of the waves generated are dependent upon the depth of the burst, the depth of the water, the charge weight and the slope of the bottom at any distance from the point of detonation. It should be noted that the above data apply only to one set of conditions; the conditions under which Test Baker was conducted.

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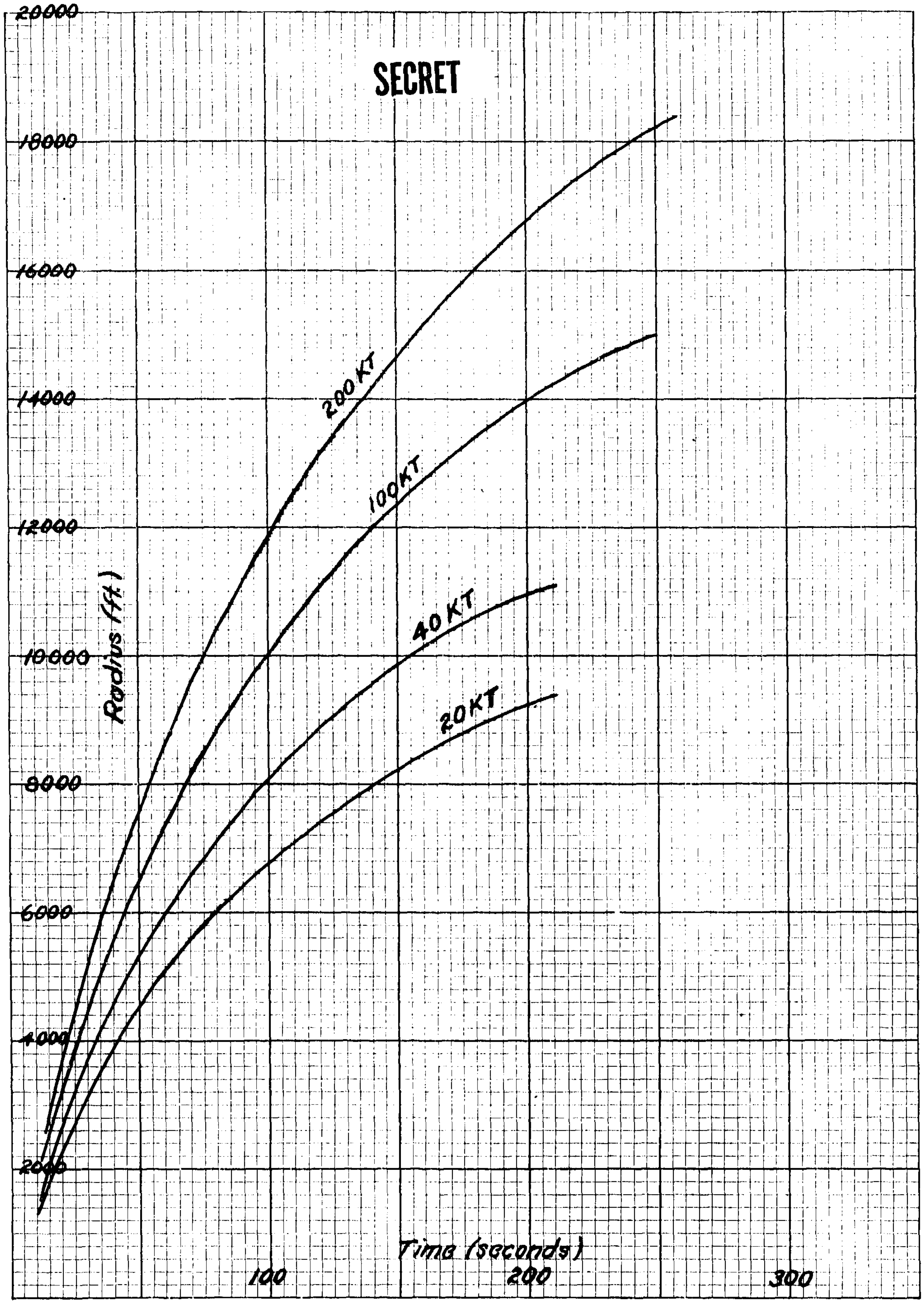

Figure 6.42 Base Surge Radius vs. Time for Various KT Yields (Mid-Depth Bursts)

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6.6 Cratering

6.61 In addition to the surface effects at Bikini, a bottom crater was formed. It has a maximum depth of 25 feet and an average diameter of 2,550 feet. Scaled experiments show that underwater bursts on the bottom in shallow water develop craters of considerable proportions. These craters should develop a lip of considerable magnitude. For example, based on scaling from TNT experiments a 20 KT bomb detonated on the bottom of a harbor, the depth of which is 50 feet, should form a crater 1,400 feet in diameter and 200 feet in depth, with a lip height of 100 feet. It is estimated that different bottom materials will not significantly affect the size of the crater, except in the case of rock bottom where the crater can be expected to be smaller.

6.62 Crater dimensions should vary with the depth of water, the depth of detonation and the charge weight. So little data is available at this time that only a qualitative statement can be made. In general, for charges detonated on the bottom, the deeper the water, the broader and more shallow the crater will be.

6.63 Under those conditions where large craters are formed, it is obvious that there will be considerable ground shock. However, no information is presently available in the amount of energy that is coupled to the earth by an underwater detonation.

6.7 Underwater Shock Waves

6.71 The shock wave formed in the water is similar to the shock wave formed in the air in that the front of the wave is vertical and the decay of pressure following the front is exponential. However, the

peak pressure in the water is much greater and the duration much shorter than in air at comparable distances.

6.72 Figures 6.72a, 6.72b and 6.72c show the variation in pressure, impulse and energy flux with distance for various KT yields detonated at great depths in deep water. These curves are based on an assumption of an infinite medium (i.e., no reflecting surfaces), and may be used to determine the pressure, impulse and energy at depths equivalent to maximum submergence of a submarine.

6.73 The reflection of the shock wave from the bottom is similar to the reflection os shock from the earth in the air. Mach stems have been observed in water as the shock wave was reflected from a denser medium. The reflection of the pressure wave from the surface is entirely different from the reflection from the bottom. When a pressure wave in water is reflected from the air-water interface, it is reflected as a rarefaction or tensile wave. At a distance which is great compared to the depth of the explosion, the rarefaction wave will cut off the tail of the compression wave thus reducing the impulse and energy at those distances. It is pointed out that the effect of "cutoff" decreases rapidly with depth in the water. Figures 6.73a and 6.73b are an illustration of the effect of the reflection at the surface.

6.74 Figure 6.74 shows the optimum depth of detonation for producing maximum energy flux at a hull depth of 15 feet for 20 and 40 KT yields. Energies maximized by those depths are given versus horizontal distance from the explosion.

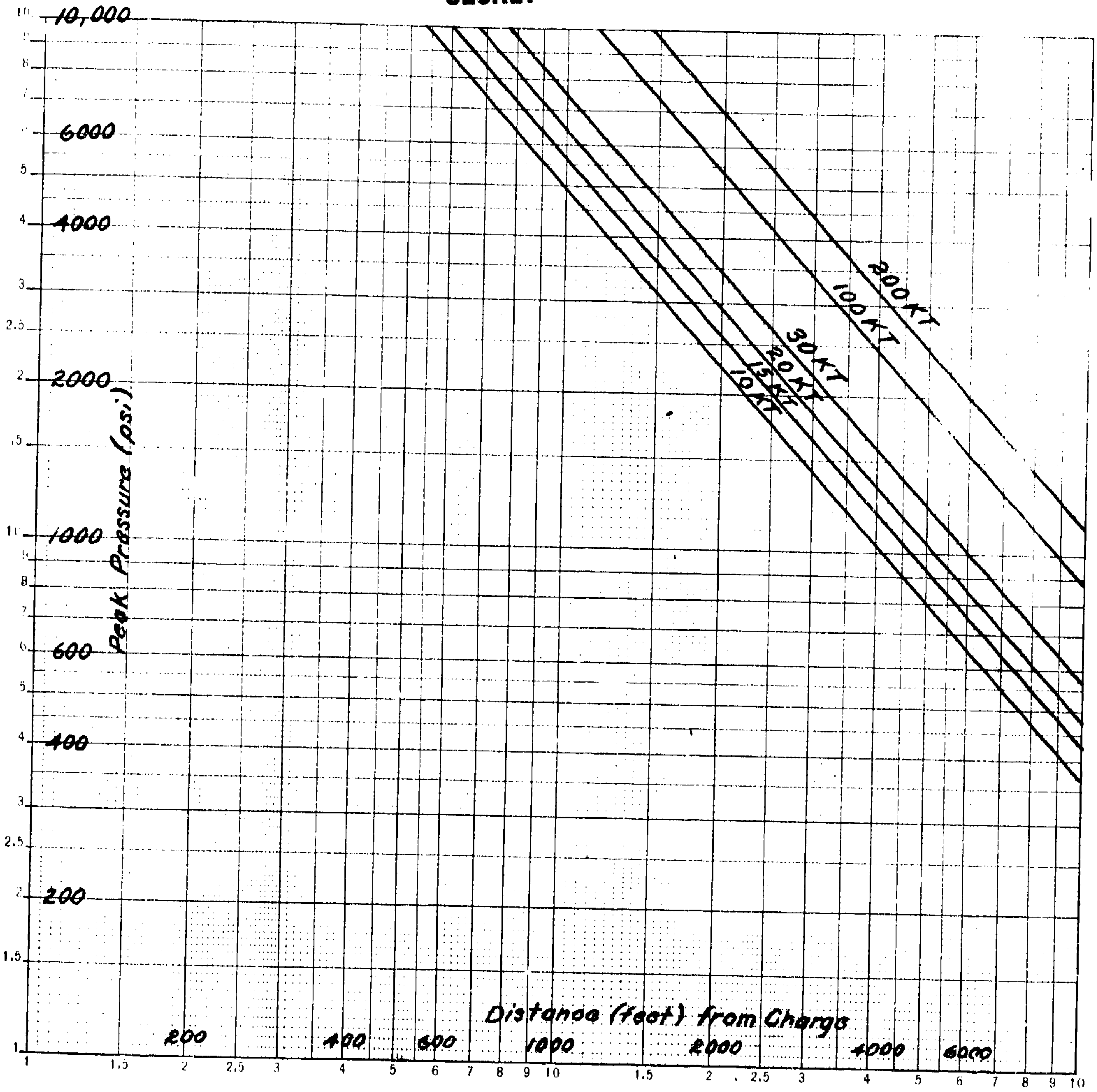

Figure 6.72a Underwater Overpressure vs. Slant Range for Various KT

...lds Burst in Deep Water

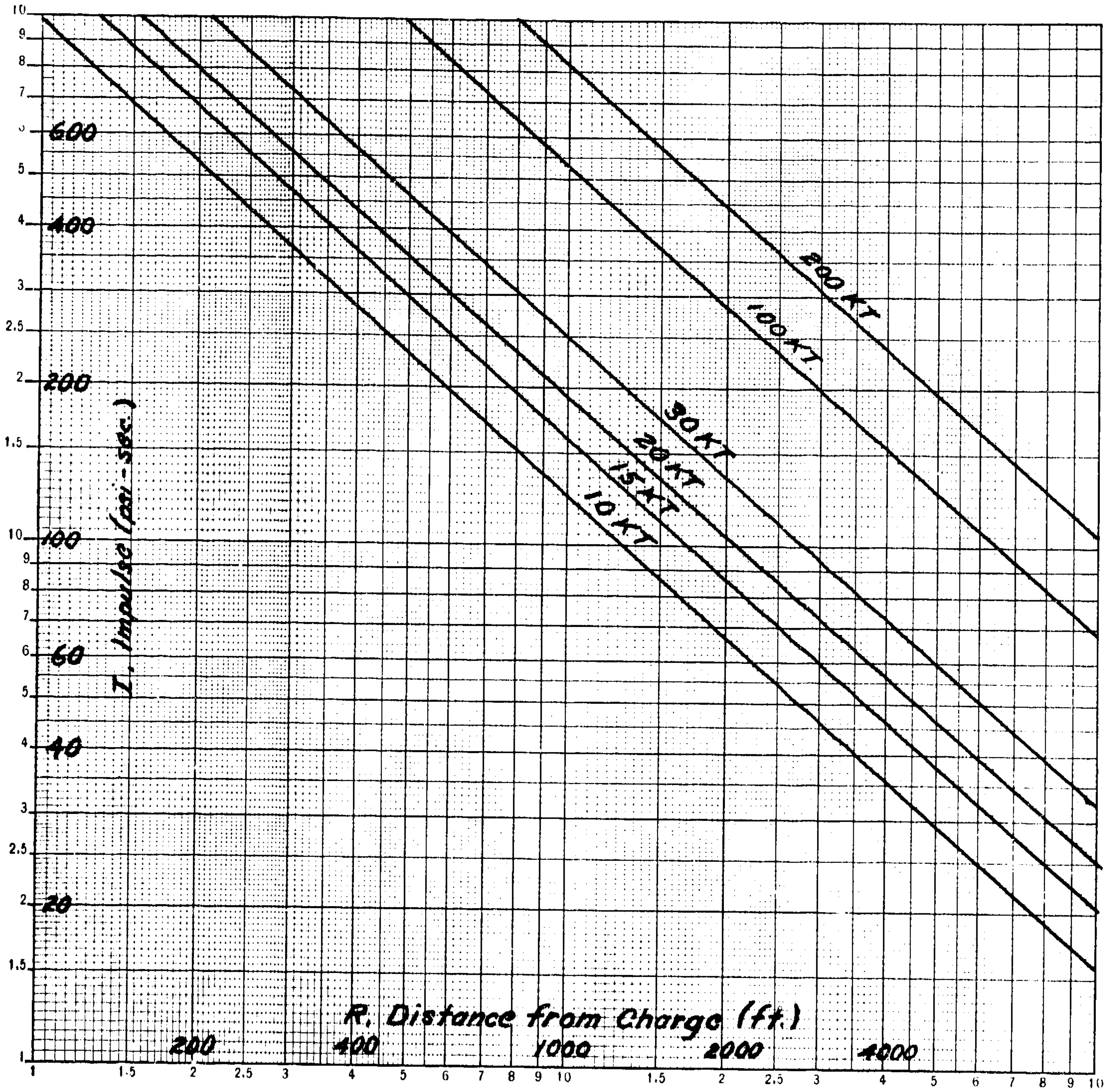

Figure 6.72b Impulse vs. Slant Range for Various KT Yields Burst in Deep Water

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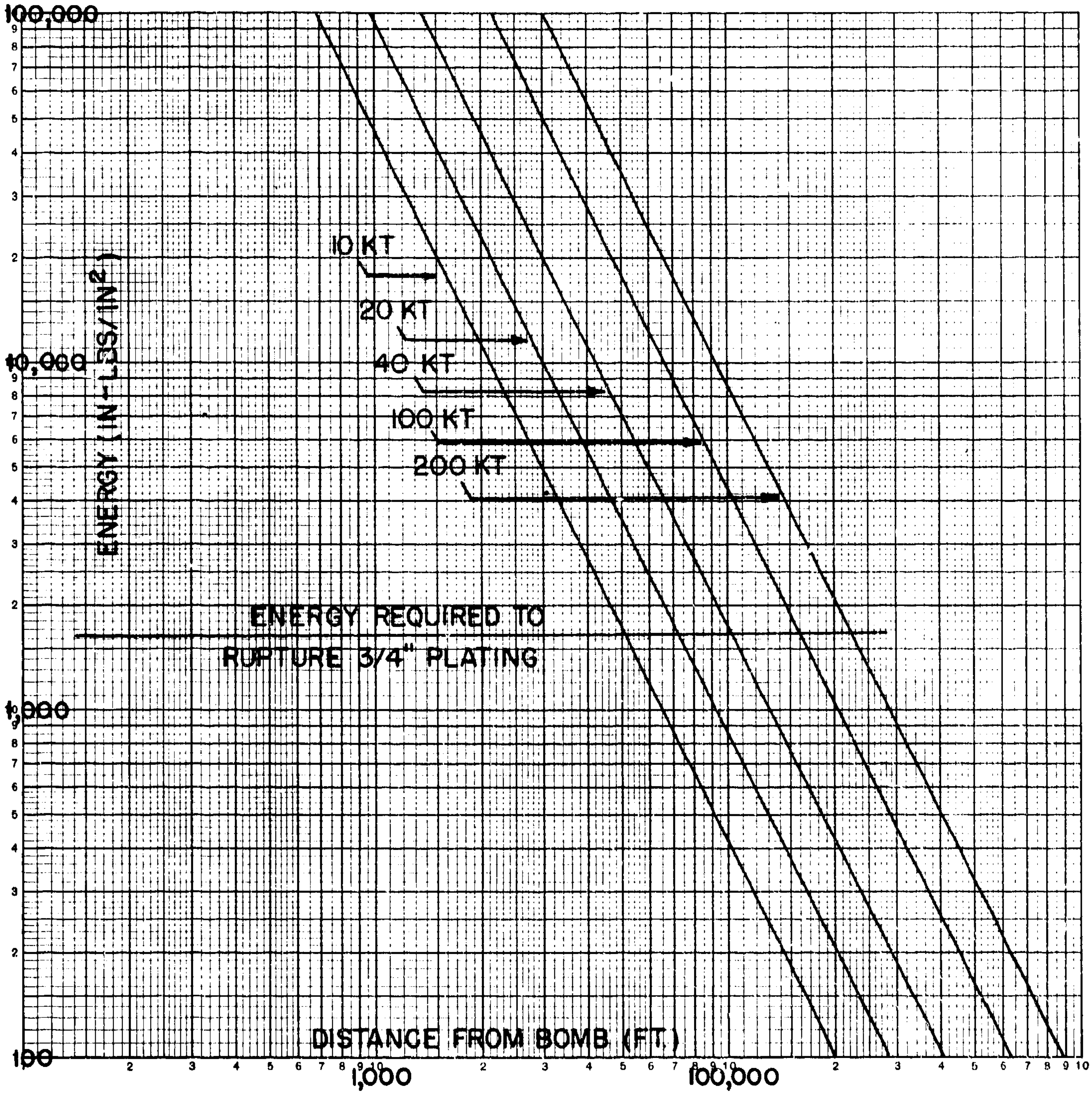

Energy Per Unit Area

vs

Distance In Deep Water

FIGURE 6.72c

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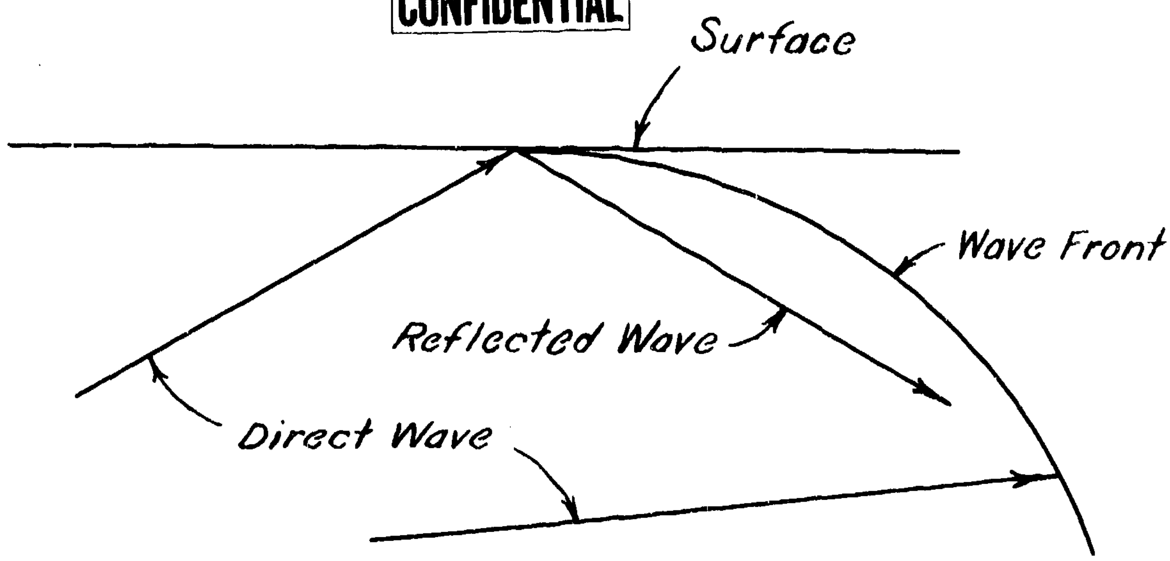

Figure 6.73a Direct and Reflected (rarefaction) Wave at Surface of Water

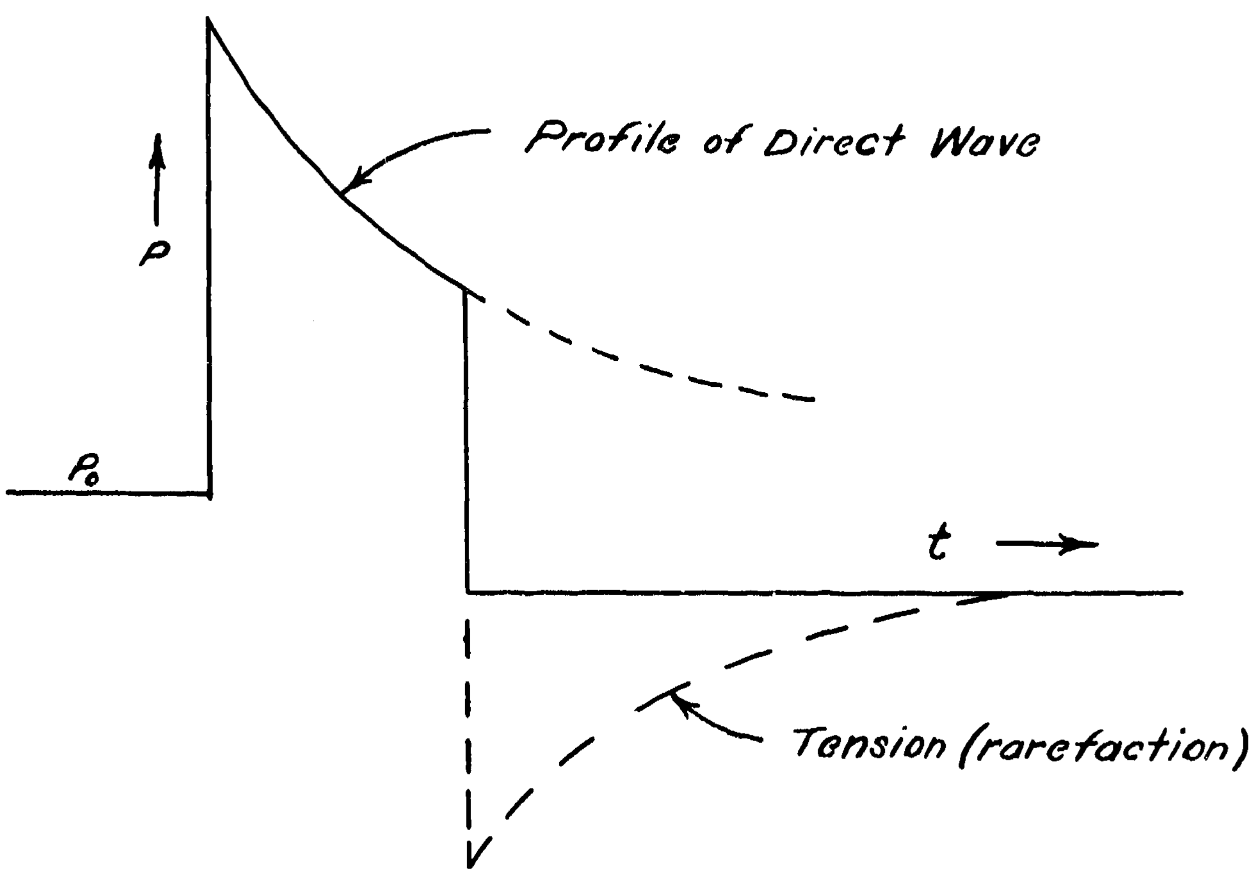

Figure 6.73b Effect of Surface Reflection on a Shock Wave Below a Free Surface

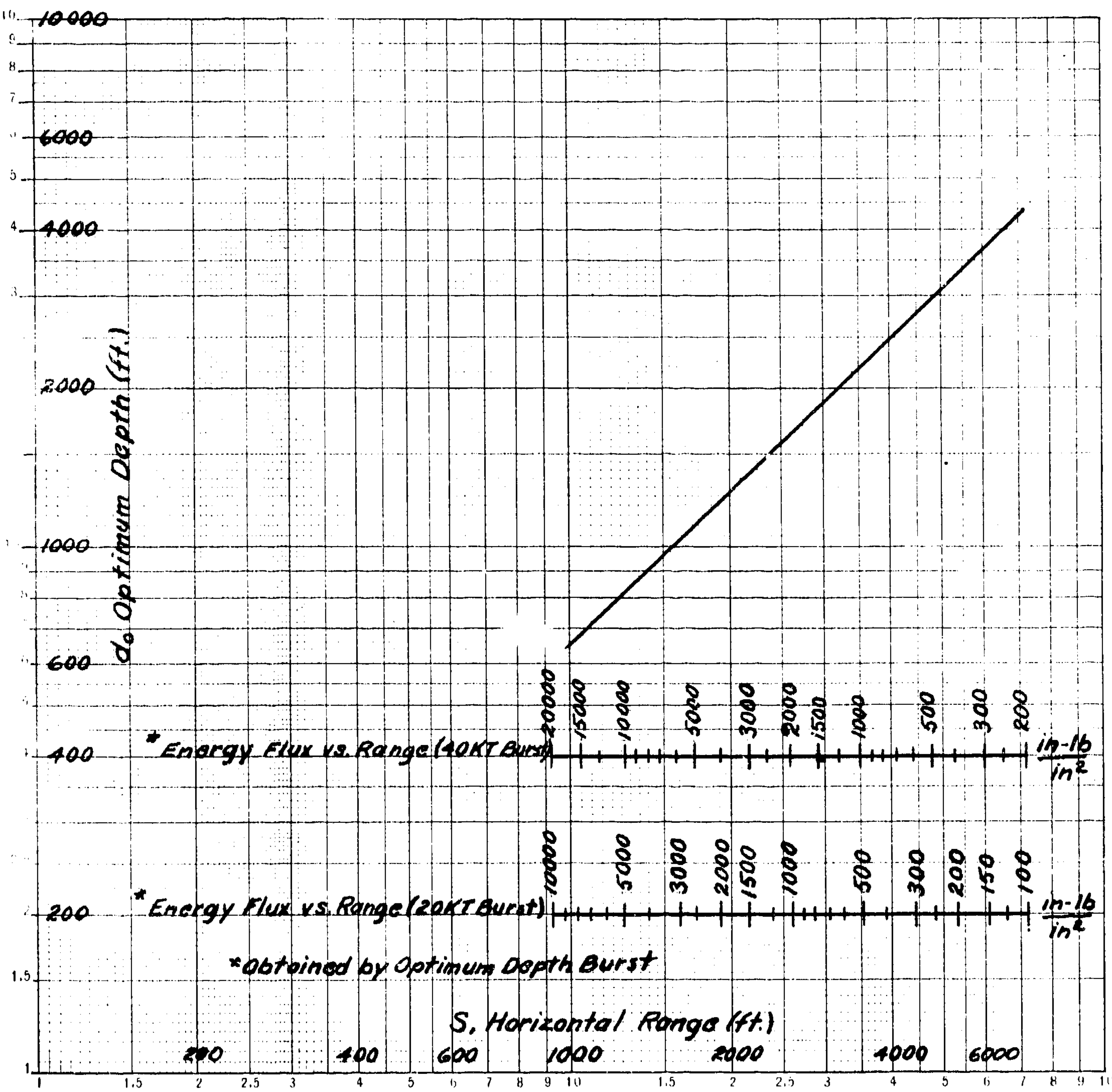

Figure 6.74 Optimum Depth of Detonation for Producing Maximum Energy Flux on Target at 15 foot Hull Depth for 20KT - 40KT Burst vs. Horizontal Range to Burst

6.75 In deep underwater A-Bomb explosions (1000 feet or greater) a phenomena known as the bubble pulse can be expected. Subsequent to the initial expansion of the gas globe in deep water, the gas bubble contracts and expands again, sending out a second pressure wave of a different shape than the primary shock wave. In general it can be stated that the bubble pulse will serve to increase damage to ships hulls or submarines. Because of limited knowledge of this phenomena in conjunction with atomic explosions, the effects of this factor are not considered in this Handbook. However, research programs are now underway which are expected to yield the necessary information to take this factor into account in the future. It is to be remembered that in an atomic explosion at a depth of less that 500 feet, there will be no bubble pulse due to the early venting of the gas bubble.

6.8 Thermal Radiation

Thermal radiation from an underwater detonation is absorbed in vaporization and dissociation of the surrounding medium. Its effects are insignificant as far as damage is concerned.

6.9 Nuclear Radiation

6.91 Initial Radiation :

For an underwater burst at moderate depths the initial gamma and neutron radiations can be ignored since they are almost completely absorbed in a few yards of water. A small amount of induced radioactive contamination will result in sea water from neutron interaction with the salt but this is insignificant in comparison to the residual radioactive contamination from fission products.

6.92 Residual Radiation :

The Bikini-Baker test provided considerable information on the potential military importance of the residual radiation from an underwater detonation. The extent of this radiation may vary considerably depending on whether the target is an adjacent land area or a ship surrounded by water. In the latter case, as at Bikini, much of the contaminated material will rapidly drain off the ships into the water where it will be relatively ineffective because of the dilution. Figure 6.92 gives the total dosage as a function of distance for a target similar to a ship afloat for a 20 KT burst in a 5 m.p.h. wind. For an adjacent land target Figure 5.72a for an underground burst would be a more reasonable estimate. A large fraction (greater than 50%) of these dosages will be received within 30 minutes of the explosion. Calculations which probably give a correct order of magnitude, at least, indicate that the dosage rate within the base surge decreases by a factor of about 400 in the interval between 1 and 4 minutes after the explosion. The decrease in dose rate from the contamination can be calculated from the decay curve in Figure 3.72c. The dose rate at one hour after detonation for a 20 KT underwater burst adjacent to a land target is estimated as the same for the underground burst in Figure 5.72b. For a ship target the dose rate would be about 1/4 as great as the same distances. The dosage received by personnel entering these contaminated areas can also be calculated using Figure 3.72d. All the dosages and dose rates will be approximately proportional to the yield of the bombs.

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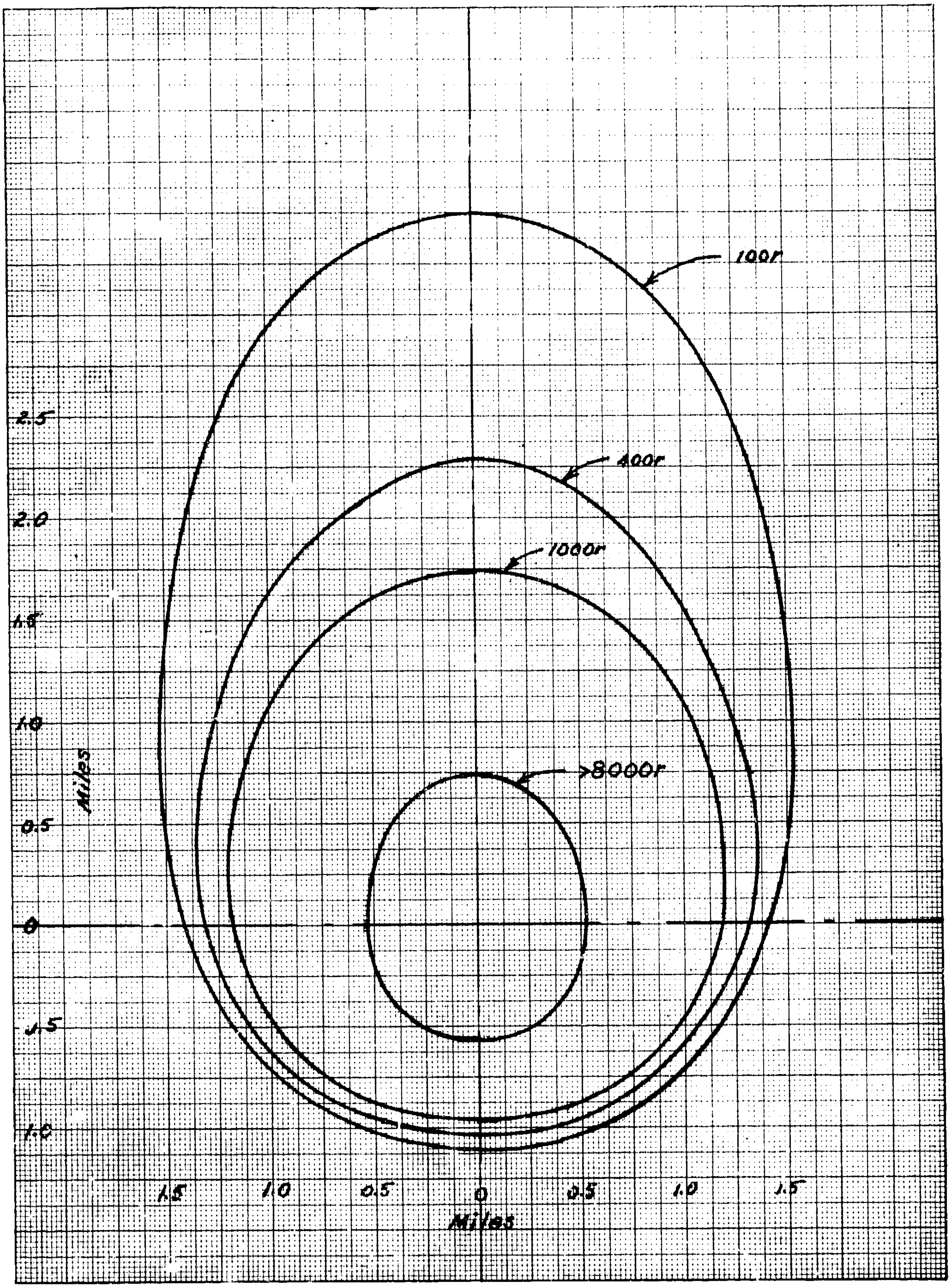

Figure 6.92 Total Radiation Dosage Contours after 20KT Surface Burst

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CHAPTER VII

EFFECTS OF TOPOGRAPHY AND ATMOSPHERIC CONDITIONS

7.1 Air Blast

7.11 Previous discussions of reflection phenomena were based on an assumption of a perfectly reflecting surface. Most targets do not approach this idealization. Although it has been determined that one structure will not shield another from the blast, it is known from practical experience at Nagasaki that large land masses will serve to concentrate the blast effects in some areas and shield other areas. If an atomic weapon were burst over hilly terrain, it would be found that, in general, structures on slopes facing the blast would suffer greater damage than those on slopes facing away from the point of detonation.

7.12 The minimum sized hill required to produce the shielding effect observed at Nagasaki is not known. Qualitatively it can be stated that the hill must be large compared to the target before any appreciable shielding can be predicted. The hills at Nagasaki were approximately 1,000 feet high. It is pointed out that the effects of the air blast may be greater on the second slope facing the point of detonation than on the protected slope nearer to the point of detonation, providing that the horizontal distance to the second facing slope is within the damage range of the bomb.

7.13 The effects of atmospheric conditions on blast are not yet known fully. However, it has been estimated from theoretical analysis that

heavy rain or fog may reduce the effective yield by as much as 50% for lower overpressures. That is to sa he range at which overpressures on the order of 5 psi are experienced would be the range a t which those overpressures would be experienced from a bomb of half the yield. The effect on the ranges of high overpesssures is not expected to be as great, and the effect on the range of very high overpressures may be insignificant.

7.14 The effect of an atmospheric temperature inversion on the area of damage is not known quantitatively, but it is predicted that such an inversion would increase the area of damage if it existed above the point of detonation. Conversely, it is predicted that an inversion would decrease the area of damage if it existed below the point of detonation. These general statements apply to all types of bursts.

7.2 Thermal Radiation

7.12 Because of the similarity of the thermal radiation from an atomic weapon and the sun, the effects of topography and the atmosphere on this radiation are the same as for sunlight when the sun is at the same height above the horizon as the height of explosion. However, at the closer ranges the fireball is relatively much larger than the sun and the shadowing effects of objects will be less. The radiant beam can upon striking matter be reflected, scattered, absorbed, or any combinations of these. Thus, those features of the terrain which provide line of sight shielding for the target will protect it from the direct thermal radiation. It should be remembered that thermal radiation may be received by a shielded target through the process of reflection

from another surface. The amount reflected will depend on the particular material under consideration and will, of course, be high for polished metallic surfaces and low for rough dark surfaces.

7.13 Fogs, smoke, and snow may radically alter the thermal energy incident on a particular surface. Some qualitative estimates of these effects are presented below:

a. Bomb radiation at distances beyond about 1,000 yards are not intense enough to burn their way through fog or smoke.

b. The Wilson cloud, which is sometimes formed, occurs too late to seriously affect the thermal radiation.

c. For a low-lying fog or smoke layer over the target, with the bomb in clear air above, the thermal radiation will be reduced under similar conditions the same amount as the sun's intensity. Fogs which will reduce the sun's intensity to 1/10 have occurred occasionally and smoke screens of this density can be made.

d. Where the fog, smoke layer, or snowstorm cover both the target and extend upward above the bomb, two extreme cases develop. If the layer is a black smoke and attenuates the radiation mainly by absorption, then it will prevent a large portion of the radiation from reaching the target. If the layer is a scattering medium with no absorption, as a water droplet fog or an oil smoke screen, and if the layer extends large distances in both the horizontal and vertical directions, then the radiation on the target is increased. Since actual conditions have been observed to consist of layers which both scatter and absorb, it is believed that some protection from the thermal energy will be offered in this situation.

e. Cloud layers above the bomb and clear air below will result in additional thermal energies on the earth's surface due to reflection from the cloud base. If the cloud is dense enough to reduce daylight to 1/10, it will increase the bomb radiation on the target by more than 80% at certain distances: Such clouds are fairly heavy but common.

f. Where there is snow on the ground but not on the target, the thermal radiation may be increased by as much as 80% due to reflection.

7.3 Nuclear Radiation

7.31 The largest fraction of the gamma radiation will travel in a straight line from the source similar to visible radiation. Therefore, irregularities of topography which will place personnel in a shadow from the point of detonation will materially reduce the effective gamma radiation distance. However, gamma rays are scattered by air so that at a distance of one-half mile about 10% of the gamma radiation dosage is obtained from rays coming from the opposite direction than the point of detonation.

7.32 Since gamma radiation is not absorbed by clouds to any greater extent than by air, the gamma ray dosage is independent of atmospheric conditions.

PART II

DAMAGE CRITERIA

CHAPTER VIII

SELECTION OF TYPE OF BURST

8.1 General

One of the problems that will confront the commander or staff officer in the field is the determination of the type of burst and bomb yield to be employed in order to obtain the maximum effects on a specific type of target. Since different types of bursts maximize different types of damage, a brief discussion of the general factors pertaining to this problem is presented in this chapter.

8.2 Comparison of Energy Distributions

In Part I the energy distribution of the various types of bursts were presented. These data are tabulated below for the purpose of comparison:

TABLE IV

Physical Effects	ENERGY DISTRIBUTION IN PERCENT Air Burst	Surface Burst Over Ground	Surface Burst Over Water	(1) U.G. Burst	(2) U.W. Burst
1. Air Blast	55	35	35	20	25
2. Thermal Radiation	30	10	10	None	None
3. Nuclear Rad.(Initial)(3)	5	5	5	5 (ineffective)	5 (ineffective)
4. Nuclear Rad.(Residual)(4)	10	10	10	10	10
5. Underground Shock	None	15	None	25	None
6. Underwater Shock	None	None	15	None	30

TABLE IV - Cont'd

Physical Effects	Air Burst	ENERGY DISTRIBUTION IN PERCENT Surface Burst Over Ground	Surface Burst Over Water	(1) U.G. Burst	(2) U.W. Burst
7. Cratering & Col.	None	10	10	15	10
8. Water Wave Formation	None	None	(Less than one percent)		
9. Fusion and/or Vaporization (Energy loss to earth or water)	None	15	15	25	20

Note 1 - U.G. Burst: Underground burst at approximately 50' below the surface.

Note 2 - U.W. Burst: Underwater burst at approximately 100' below the surface.

Note 3 - Nuclear Rad.(Initial): In the U.G. and U.W. burst the initial radiation is completely absorbed by the surrounding medium and consequently will not be capable of producing useful damage.

Note 4 - Nuclear Rad.(Residual): In the air burst, residual radiation is dissipated in the atmosphere. However, in the other types of burst part of the radiation is in the form of a radiological contamination of the earth or water.

8.3 Comparison of Main Effects

From the above tabulation it is indicated that for all the weapons having the same KT yield:

8.31 An air burst maximizes air blast and thermal radiation effects and minimizes residual contamination. In a built up area, a considerable number of casualties will be inflicted by secondary effects, such as flying debris

and secondary fires. This type of burst should be employed for maximum destruction of surface structures, equipment, material and personnel.

8.32 A surface burst sacrifices some of the air blast and thermal radiation energy to the earth and water for cratering, earthshock, watershock, waves, etc. (Note: For the same quantity of fissionable material, a surface type weapon will have much greater yield than a penetrating type weapon. It is possible that a surface burst type weapon will produce as much damage through ground and water shock as the penetrating type weapon because of its greater yield.) The surface burst maximizes destruction in the immediate vicinity of the point of detonation. There will also be considerable residual contamination which, except for passage through, is capable of denying a considerable area to personnel.

8.33 The underground burst maximizes ground shock, cratering and ground contamination at the expense of a reduction in the air blast and the elimination of all thermal and instantaneous nuclear radiation. Casualties from secondary missiles may be expected. This type of burst will maximize damage to underground structures, and radioactive contamination.

8.34 The underwater burst maximizes water shock, and residual contamination at the expense of a reduction in air blast and the elimination of all thermal and instantaneous nuclear radiation. In addition, damage by wave action should be considered. Residual contamination will cover a large area due to the formation of the base surge.

8.4 Burst Selection

8.41 From the above, it is evident that the type of burst to be employed

depends on the specific target and the types of effects to be maximized. Furthermore, several other items must be taken into consideration:

a. Delivery methods available.

b. Possible delivery errors.

c. Nuclear efficiency. The highest efficiency is usually desired where possible.

d. Relative importance of permanent and transient effects.

e. Safety of friendly forces.

f. Atmospheric and topographical influences.

g. Availability of weapons.

A preliminary analysis of the tactical situation will dictate the relative importance of the above items, thus enabling the selection of the possible type of bursts to be employed. The various effects from these bursts are then compared and the final choice made. It is felt, however, that in the majority of cases an overriding factor will be present which will determine the type of burst to be employed, thus eliminating the time and effort necessary to make a detailed comparison of types of bursts for a specific target.

CHAPTER IX

PRINCIPAL DAMAGE PARAMETERS

9.1 Air Blast Damage

9.11 Peak Overpressure as a Criterion :

a. One of the advantages of an atomic explosion as compared to the explosion of a conventional bomb is the long duration of the positive pressure phase of the former. The response of any structure to air blast is dependent upon the overpressure, the time during which that overpressure acts, and the fundamental period of vibration of the structure. If the period of vibration of a structure is considerably less than the duration of the positive pressure phase of the blast wave, peak overpressure is the criterion for determining the response of the structure (assuming the structure is in the region of sufficient impulse). This is the case with an atomic bomb for approximately 95% of all structures. Part I contains the relationship between bomb yields, distances, overpressures, and the duration of pressure phases.

b. Personnel are very resistant to the shock wave, requiring in the neighborhood of 150 p.s.i. for death with relatively little damage at lower overpressures. However, the effects of flying objects (secondary blast damage) can create large numbers of casualties. This effect depends to a large measure on target composition.

9.12 Impulse as a Criterion :

a. The summation of the pressure times the time is impulse, and it is abvious that the longer the duration of the shock wave, the less the pressure required to produce the same impulse. For blast waves of short duration (HE explosions), the impulse is the criterion for damage. Less than 5% of all structures have fundamental periods of vibration greater than the duration of the positive pressure phase of the air blast from an atomic weapon. Some structures with long periods of vibration are tall chimneys, long span suspension and cantilever bridges, and tall thin buildings. For those cases, impulse is the criterion for damage.

b. In order to simplify the use of this handbook in those cases where impulse is the criterion, computations have been made to determine the peak overpressure at which the required impulse is obtained. Therefore, damage with either overpressure or impulse as the criterion is all tabulated as a function of peak overpressure.

9.2 Ground Shock Damage

9.21 Energy Ratio as a Criterion :

a. In general, three main criteria pertaining to damage due to ground vibrations have been employed. The criteria are:

(1) Energy Ratio (Crandell's Index of Damage. To be used with Figures 3.56a and 3.56b.)

Energy Ratio	Damage
15 or greater	Serious
9 to 15	Moderate
6 to 9	Light

This index indicates that soil type is an extremely important factor in damage criteria.

(2) Acceleration (Thoenen and Windes Index of Damage. To be used with Figure 3.52a.)

Moderate damage for accelerations above 1g.

It is suggested that Energy Ratio is preferable to this Index.

(3) Displacement (Leet's Index of Damage. To be used with Figure 3.55.)

Moderate damage for displacements greater than .03 inches.

It is suggested that this Index is less applicable than both Energy Ratio and Acceleration Indexes.

It is noted that energy, accelerations, and displacement are interrelated. This handbook will use the energy ratio as the criteria because it can be expressed as a function of both the displacements and the accelerations involved.

b. In order to furnish some concept for the rather abstract term "energy ratio", a brief description of the E.R. involved in an earthquake is described below. Based on the destructive earthquake of 1933, Long Beach, California, the Coast and Geodetic Survey found that the acceleration was approximately 3 ft/sec^2, and the frequency about one cycle per second in the basement of buildings, establishing an E.R. of 9. This E.R. was sufficient to demolish wall-bearing buildings, chimneys, porches on frame structures, produced damage to (and in some cases collapse of) water tanks, and caused some but not excessive breakage in underground utilities. Further,

from experience to date, it is indicated that an E.R. below 3 will cause no damage to buildings of sound construction and material. Observations also indicated that brick piers, wall-bearing buildings and chimneys will fail before wooden frame buildings. Underground facilities, particularly water mains, would suffer greatly from displacement and the pressures exerted. It is to be expected that electrical mains would suffer much less due to their ductility but above ground lines would be damaged because of the collapse of towers and poles.

c. While the knowledge of damage criteria for ground vibrations is extremely limited, it is known that the frequency of the vibration in the ground is a potent factor in determining the amount of energy transmitted to structures. It is desired to emphasize that the damage criteria for E.R. presented in this book are based on very limited data and therefore a considerable safety factor has been injected into Damage Table VIII. Until large-scale tests can be completed, the criteria presented here will have to serve as planning values.

9.22 Crater and Throw-Out Damage :

a. An atomic explosion either on the surface or underground will create a crater of considerable size. This large crater should be a useful effect on certain types of targets, especially massive permanent installations of the concrete and steel type. It is to be remembered that the area surrounding the crater will be very radioactive and thus seriously hamper any attempts to repair items in the area.

b. An additional damaging feature of the surface and underground

burst is the throw-out associated with the crater formation. The missile damage from throw-out will depend to a large extent on the soil conditions and the target materials involved in the immediate area of detonation. Sandy soil will provide few missiles while rock formations will break up into excellent missiles. It is estimated that missile damage can extend in radius to two or three miles. The missile density will, of course, decrease with distance.

9.3 Underwater Shock Damage

9.31 General Criterion for Damage :

In an underwater explosion, the major portion of the energy goes into the formation of the primary shock wave in the water. This shock wave in the water is the principal cause of damage to ships, submarines, and underwater structures. As previously explained, the underwater shock wave has much higher pressures but much shorter durations than the air shock wave. Thus, in general, the fundamental periods of vibration of ships, submarines, and underwater structures is greater than the duration of the positive phase of the underwater shock wave. Therefore, impulse and/or energy becomes the criterion for damage caused by underwater shock.

9.32 Effect of Hydrostatic Pressure :

The tremendous increase in hydrostatic pressure with depth is well known. It is desired to point out that those targets which are already subjected to a large hydrostatic pressure load due to submergence may fail with only a small additional load imposed by the shock from the bomb. Submarines constitute an important target which may be subjected to large

hydrostatic stresses at the time of bomb detonation. It will be shown later how the lethal radius for submarines will increase with depth of explosion (down to optimum depth) and the depth of submergence.

9.33 Shallow Water Effects :

a. It is expected that underwater detonations in shallow water, such as harbors, will cause extensive damage to shore installations and piers due to ground vibrations and large waves. No data on theoretical estimates of the damage to be expected from these ground vibrations are available at this time. Some wave data is known and is presented in Chapter IV along with some wave damage information in Chapter VI. In general, these are no different from ordinary waves except that large ones may be produced in normally quiet harbors.

b. Insofar as destruction to structures adjacent to the shore is concerned, the wave velocity is an important factor. The velocity of six feet per second represents a lower limit for damage. Since the velocity of a wave in shallow water is a function of the wave height and the water depth, it may be assumed that waves high enough to reach the structures on the shore will cause damage. The higher the wave that impinges on the structure, the greater the damage.

9.4 Thermal Radiation

9.41 General :

a. That part of the bomb's energy radiated as heat energy is probably the most unpredictable of the three effects. The thermal energy which will arrive at a point in space from a particular yield and through a known

atmospheric condition is well known, but the exact condition of the target is the uncertain factor. A small uncertainty in the target condition will not greatly affect the damage expected from blast or nuclear radiation but might alter radically the thermal damage. This is mainly due to the ease of shielding of the thermal rays and to great variability in susceptibility of materials to thermal damage. Most targets must be approached from the probability point of view for thermal damage. As explained below, when the thermal energy arrives over a short period of time, as is the case with an atomic explosion, the total energy received is the important damage criteria.

b. An important item to be considered here is the amount of the incident energy which is absorbed by the target material. It is only the energy which is actually absorbed that causes the damage. In general, the color of the surface is the principal factor that determines the amount to be absorbed and reflected. The light or white colors absorb the least and the darker colors absorb the most. For example, a dark blue uniform may absorb 2 or 3 times as much thermal energy as a white one.

c. For those targets which contain their own source of fire, such as cities, secondary fires are often of major importance in the ultimate destruction which is inflicted. The blast wave will so alter the target material as to increase its inflammability and at the same time bring the internal fire sources into contact with this material. Some important internal fire sources are heating equipment, electrical equipment, etc.

9.42 Material :

a. The damage resulting from the heat energy is mainly a surface effect. This is due to the fact that these large pulses of energy arrive in a very short period of time (a few seconds) and will, therefore, only heat up the surface of the target. When a material is subjected to thermal energy in this manner, the criteria for damage is mainly the total thermal energy applied. Since most of the ultraviolet light is absorbed before striking the target, the chemical processes associated with this frequency of light (such as skin tanning) are absent and only temperature rise of the surface occurs. As a result of this process, the surface may experience several effects depending on the material and surface conditions involved. The surface may melt or bubble as in the case of plastics; it may scorch or burst into flame if it is inflammable; or in the case of metals, nothing of importance will occur except perhaps a paint scorch. It should be remembered that atmospheric condition, especially humidity, can greatly alter the heat damage. The moisture content of materials will often determine the fire susceptibility. It is obvious that a dry forest, for instance, will catch fire much easier than a moist one. Considerable data are available relating the degree of damage and incident thermal energy involved.

b. When the source of heat disappears, the destruction from fire of materials having the same composition, moisture content, initial heat flux, etc., will depend on another important parameter, namely, geometry of the surface. It is a well known fact that a plane surface will not support a fire. It is necessary to have several surfaces which face each other in

order to sustain a fire. This is because reradiation between surfaces is necessary to maintain the temperature high enough for combustion. Therefore, fires started on a plane surface will extinguish themselves unless something changes the geometry.

c. The arrival of the blast wave at the fire surface may have a profound effect on the final result. It is seen from previous chapters that at the more important distances, the thermal energy will have arrived before the blast wave. Therefore, it is believed, but never investigated, that the blast wave may extinguish the majority of flash fires, but will also rearrange the material into a very inflammable configuration so that only a few fires need survive in order to produce a large general fire in some target areas.

9.43 Personnel :

a. In a tactical situation, especially during ground operations, it is felt that the casualties from thermal radiation may be a most important product of the bomb. The number and seriousness of these casualties, however, will be extremely difficult to predict. The amount of energy necessary to cause various skin damages is known along with the amount necessary to cause damage to clothing materials. Of major importance in analyzing the casualty-producing effect of a thermal flux is the actual percent of body surface area involved in thermal injury. While a thermal injury of one side of each hand and one side of the head will not produce a burn of 10% of the body surface area, it is felt that this will be sufficient, in most cases, to result in an immediate casualty, but not death. Thus, it is evident that the percentage

of casualties from thermal radiation will vary with the uniform involved which, in turn, is a function of the climatic zone, season of the year, and the particular military operation under consideration.

b. Under certain conditions the effect of flash blindness may be a factor to consider in estimating the effects on personnel within certain ranges. It is not possible to predict the exact results but the following qualitative facts are known to be reasonably true. These statements are true for ranges of 2 to 3 miles, except in smoke or fog, and yield of 20 to 100 KT. A flash of approximately 800 - 1000 suns will result.

Daytime operations:

(1) If the fireball is in the forward field of vision, a loss of precise vision will occur for periods of 5 to 10 minutes, i.e., mobility may be accomplished but sighting ability is impaired.

(2) If the fireball is not in the forward field of vision, then no sight impairment is expected.

Night operations:

(1) If the fireball appears in the forward field of vision, it is expected that considerable impairment will persist for a period of one hour or more.

(2) If the fireball does not appear in the forward field of vision, then impairment of night vision is expected for 15 minutes or more.

9.44 Thermal Shielding :

a. As stated above, little effort is required to shield a target from thermal radiation. Almost any material will withstand the thermal flux long enough to shield an object behind it. For large areas, smoke screens are excellent energy absorbers as described in Chapter VII. It is believed desirable to point out that many targets contain openings through which thermal radiation may pass, such as windows in buildings and plexiglas domes in aircraft. While the general target may not be damaged by external heat, these openings may allow damaging amounts of energy to strike a vulnerable interior material. Any substance through which the eye can see will transmit the majority of the incident energy.

b. In certain special cases (for example, a foxhole) significant amounts of thermal radiation may strike by reflection a target with line-of-sight shielding. It has been estimated that 10 - 15% reflection from the rear wall of a foxhole is quite possible. Protection from thermal radiation should, whenever possible, be taken in advance of the detonation. However, since the thermal radiation arrives over a significant time period, it is possible to reduce the exposure by sudden evasive action at the time of detonation.

9.5 Nuclear Radiation

9.51 General :

The nuclear radiation effects of an atomic explosion may be divided into two categories as described in previous chapters, namely, the instantaneous (neutrons and gamma rays) and the residual (gamma rays, beta and alpha

particles) radiations. These rays and particles all ultimately produce the same effects on human tissue, but because of their different ability to penetrate the human body, their mode of action will differ. In general, gamma rays and neutrons produce their effects from outside the body (external radiation) while alpha and beta particles are only effective when the emitting radioactive material is absorbed within the body (internal radiation). This can only be accomplished by inhalation or ingestion of the radioactive material or by wound contamination. Furthermore, internal radiation generally requires a much longer time to produce any serious harm to personnel and for these reasons is of little military importance. Occasionally the beta and alpha radiations may provide some long-term hazard to permanent occupation of a contaminated area.

9.52 Material :

Nuclear radiations do not produce any important direct damage to material except insofar as they may render the material unsafe for human use. Contamination by alpha, beta, and gamma emitting radioactive materials is entirely a surface effect. Neutrons are the only nuclear radiations which can produce any actual change (induced radioactivity in inanimate materials). Except in the case of induced radioactivity, all contamination can be removed by some cleansing or surface removal procedure. Because of the limited range of neutrons as compared to the ranges for other effects, the material damage resulting from them can be neglected.

9.53 Personnel :

a. The most important criterion for producing damage to personnel is

the dosage which is received. Thus, a person operating in a contaminated area with a dose rate of 400r/hr could operate for 1/4 hour and receive a dosage of only 100r. This might produce little harm but if he stayed in the area for 1 hour, he would receive a dosage of 400r and would probably become a serious casualty and stand a 50% chance of dying. Because of this time - dose relationship, it is difficult to deny traversal of an area by contamination since one may operate in a relatively highly contaminated area so long as he remains in the area only a short time. Contamination is more effective in hindering repairs to damaged structures where the operating time in the contaminated areas must necessarily be quite long.

b. While the total dosage is the primary criterion for personnel damage, it is true that if the time of exposure increases, then the total dosage required to produce casualty also increases. Thus, 400r received in an instantaneous exposure will produce 50% eventual death. However, 400r received at the rate of 20r/day for 20 days will produce few, if any, deaths and only a limited number of casualties. Another factor to be considered is that the gamma radiation dosage rate in a contaminated area will decrease with time, thus decreasing the military effectiveness of the contamination. As shown by Figure 3.72c this decrease is very rapid immediately after the detonation but becomes slower as time passes.

9.54 Protection :

a. Protection against gamma radiation is far more difficult to achieve than protection against thermal radiation since large masses of material are required to appreciably absorb the gamma rays. Clothing provides essentially

no protection against gamma radiation. It should be remembered that it is the weight of the shielding material and not the specific material that is the important criteria in determining the effectiveness of any gamma ray protection. Line of sight (shadow) shielding will be quite effective in providing protection from the initial gamma radiation unless very large shielding factors are desired. In the latter case, the shield should completely surround the individual since about 10% of the rays do not come directly from the point of detonation. It is important to keep this in mind when considering what protection can be obtained from a foxhole. In the case of the underground or underwater explosions where the gamma ray sources are the cloud, base surge, or contaminated area, then shadow shielding will be completely inadequate. In these cases, however, the radiations are not likely to be as penetrating as the initial radiations and smaller thicknesses of shielding material may be required.

b. Protection against the internal radiation from beta and alpha particles can be obtained by the normal gas mask used as protection against CW and BW. These are equally effective in removing radioactive particles as non-radioactive.

CHAPTER X

CRITERIA FOR DAMAGE

10.1 General

10.11 It has been the purpose heretofore to present the best available data on the effects to be expected from an atomic explosion of any size under any condition of burst. An attempt has been made to indicate the reliability of these data and to point out those factors which more often than not will seriously alter the expected effects under a particular situation. It is desired to strongly emphasize that many of these data are from scale experiments, theoretical analysis, extrapolation of full-scale tests, and opinions of those most closely connected with these problems. It is evident that certain safety factors will have to be added to the damage criteria depending on the source of the data and the importance of the target. It is, of course, impossible to give any set of rules for the use of a safety factor, thus each situation will have to be evaluated with this in mind. An obviously safe rule to employ is to use one set of values for damage to the enemy and another for damage to friendly forces.

10.12 In order to treat and present the bomb effects in an orderly manner, it has been necessary to consider those effects separately. This is, of course, not the case in an actual target. All of the bomb's effects are present to some degree on each target and arrive in a precise time sequence which must be considered. For an example, a fire started by thermal

radiation in the first two or three seconds will receive a shock wave followed by wind. This may extinguish the flames or may alter the target to increase its inflammability to a few fires which might survive the blast wave. Here again, no general rules are available and each target configuration and situation must be considered separately.

10.2 Description of Damage

10.21 The most difficult operation in atomic target analysis is the description of the damage to be expected. This is due mainly to two things: Lack of knowledge of the exact target, and the fact that damage is not absolute but can cover a wide range. Since most military equipment is a complex system of many parts, it is obvious that some are usually more vulnerable than the rest. Thus, it is often not necessary to destroy the entire item to render it ineffective. Personnel associated with some equipment may be the vulnerable item. It also depends upon what function it is desired to impair and the degree of impairment needed for the particular situation at hand. Insofar as possible an attempt will be made to describe the damage expected from certain criteria and to point out the more sensitive elements. In some cases specific damage can be presented which was obtained under full-scale tests but in many cases general damage is all that can be described at this time.

10.22 Three general classifications of damage which are useful for many material items are:

a. Severe Damage.

That damage which is severe enough to completely prevent the

accomplishment of any useful military function and to which repair is essentially impossible.

b. Moderate Damage.

That damage which is sufficient to prevent any military use until extensive repairs are effected.

c. Light Damage.

That damage which will not seriously interfere with its immediate military operation but some repair will be required to restore the item to complete military usefulness.

10.23 The damage expected from the blast wave is dependent entirely on the strength of the material involved, the size, the configuration, etc.

10.24 In the case of thermal radiation it is mainly the character of the material which determines the initial thermal damage. A list of common materials and the energy necessary to cause certain degrees of damage is shown below:

*TABLE V

Material	Effect	Energy Required cal./cm.^{2}
Skin	(1st Degree Burn	2 - 3
	(2nd Degree Burn	3 - 4
	(3rd Degree Burn	8 - 10
White Paper	(Chars	8
	(Burns	10
Black Paper	Burns	3

*TABLE V - Cont'd:

Material	Effect	Energy Required cal./cm.^{2}
Douglas Fir	(Chars (Burns	8 11
Douglas Fir (stained dark)	Burns	3
Philippine Mahogany	(Chars (Burns	7 9
Maple (black)	(Chars (Burns	8 25
Cotton Shirting (gray)	(Scorches (Burns	8 10
Cotton Twill	(Scorches (Burns	10 17
Gabardine (green)	(Brittle (Burns	7 10
Nylon (olive drab)	Melts	3
Rayon Lining	(Scorches (Burns	3 8
Wool Serge (dark blue)	(Nap gone (Loose fibers burn	2 7
Worsted (tropical khaki)	(Nap melts (Burns	4 15
Rubber (synthetic)	Burns	8
Lucite	Softens	72
Bakelite	Chars	75

*This is experimental laboratory data.

10.25 Table VI is used to show the relationship between an instantaneous dose (less than 24 hours) and the probable effect on military personnel. Table VII gives the probable effects of whole body gamma radiation from doses acquired over a considerable period of time.

TABLE VI

PROBABLE EFFECTS OF ACU WHOLE BODY GAMMA RADIATION DOSES

Acute Dose	Probable Effect
100 r	Blood cell changes. Vomiting and nausea for about one day in approximately 5 - 10% of personnel. No personnel need evacuation and all able to perform duty.
150 r	Vomiting and na sea for about one day in approximately 25% of personnel. No personnel evacuation is expected.
200 r	Vomiting and nausea for about one day in approximately 50% of the personnel. Evacuation of about 25% at the end of a week will be required. Plan to relieve all men from front line activity after one week if possible. No deaths anticipated.
300 r	Vomiting and nausea in all personnel on first day. All of the group need to be evacuated by the end of the week. Twenty percent deaths may be anticipated.* Survivors ineffective for full military duty for about three months.
400 r	Vomiting and nausea in all personnel and evacuation of about 50% of personnel on first day. All of the group need to be evacuated as soon as possible. 50% deaths may be anticipated.* Survivors ineffective for full military duty for about six months.
600 r	Vomiting and nausea in all personnel within 4 hours. Evacuation of all personnel on first day. Up to 100% deaths may be anticipated. Any survivors ineffective for full military duty for over six months.

TABLE VI - Cont'd:

PROBABLE EFFECTS OF ACUTE WHOLE BODY GAMMA RADIATION DOSES

Acute Dose	Probable Effect
1000 r	Vomiting and nausea in all personnel in 1 to 2 hours. All of group need immediate evacuation. There will probably be no survivors.
Greater than 1000 r	Vomiting within first hour. All of group will be fatalities.

*The percentage of deaths will be reduced with adequate medical treatment. The majority of deaths which do occur will be in the period of 2-6 weeks after exposure.

TABLE VII

PROBABLE EFFECTS OF CHRONIC WHOLE BODY GAMMA RADIATION DOSES

Daily Chronic Dose	Days Exposure	Total Dose	Acute Dose Equivalent
60 r	6	360	300
30 r	5	150	100
30 r	14	420	300
15 r	12	180	100
15 r	32	480	300

10.3 Damage Criteria

10.31 The tables presented in this section show various target items, their criteria for different degrees of damage and pertinent remarks. The items are listed in alphabetical order for each type of military operation. An attempt is made to give the source of the data by use of numbers to the right of the damage criteria. The key of this numbering system is indicated below:

a. Full-scale test data (including Hiroshima and Nagasaki . . (1)

b. Estimates made from scale experiments . . . . (2)

c. Theoretical analysis . . . . (3)

d. Consensus of qualified persons . . . . (4)

10.32 For those items not included in Table VIII, select the listed item most similar in those characteristics discussed previously as being the important factors in determining the extent of damage to be expected. Perhaps the most important item to be remembered when estimating effects on personnel is the amount of cover actually involved. This cover depends on several items; however, one factor is all important, namely, the degree of forewarning of an impending atomic attack. It is obvious that only a few seconds warning is necessary under most conditions in order to take fairly effective cover. The large number of casualties in Japan resulted for the most part from the lack of warning.

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TABLE VIII

PART I. LAND OPERATIONS

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
Artillery Field (75mm or greater)	Severe	40 (1)	——	——	S: Damage to Gun and Cradle
	Moderate	30 (1)	——	——	M: Damage to Recoil and Carriage
	Light	5 (1)	——	15 (1)	L: Damage to Gun Sights, Paint Scorched
Artillery Field (Less than 75mm)	Severe	25 (1)	——	——	S: Damage to Gun and Cradle
	Moderate	15 (1)	——	——	M: Damage to Recoil and Loading Mechanism
	Light	5 (1)	——	15 (1)	L: Damage to Sights, Paint Scorched
Artillery (AA)	Severe	30 (1)	——	——	S: Damage to Gun and Cradle
	Moderate	20 (1)	——	——	M: Damage to Recoil and Carriage
	Light:	5 (1)	——	15 (1)	L: Damage to Electronic Equipment, Paint scorched
Ammunition in Field Dumps	Severe	10 (1)	——	20 (1)	S: Damage due to Ammo being thrown about and possible fires
	Moderate	3 (1)	——	15 (1)	M: Damage due to displacement, secondary effects and heat
	Light	2 (1)	——	10 (1)	L: Small portion damaged due to secondary effects and heat
Bridges (side on blast)	Severe	20	30 (4)	——	S: Bridge collapses. End on blast requires 60 psi
	Moderate	15	25 (4)	——	M: Bridge Displaced. End on blast requires 45 psi
	Light	—	——	——	

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TABLE VIII, PART I (Cont'd)

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
Electronic Equipment and Radars	Severe	10 (1)	—	—	S: General destruction. Field Sets thrown about
	Moderate	5 (1)	—	—	M: Antennas blown off
	Light	3 (1)	—	15 (1)	L: Paint and plastics scorched
Dumps (Rations)	Severe	10 (4)	—	20 (1)	S: Boxes thrown about
	Moderate	5 (4)	—	15 (1)	M: Fires from flash and secondary sources
	Light	3 (4)	—	10 (1)	L: Surface damage only
Dumps (Gas & Oil)	Severe	15 (4)	—	—	S: Container thrown about. May have secondary fires
	Moderate	10 (1)	—	—	M: Containers thrown about to a lesser amount
	Light	5 (1)	—	15 (4)	L: Scorching and distortion of containers
Engineer Equipment (Heavy)	Severe	50 (4)	—	—	Heavy construction and repair equipment such as bull dozers, etc., is referred to here.
	Moderate	30 (4)	—	—	
	Light	—	—	15 (1)	L: Paint scorched and seats burned
Landing Mats (steel)	Severe	14 (1)	20 (4)	—	S: Mats twisted and buckled
	Moderate	—	—	—	
	Light	—	—	—	
Landing Strips Concrete	Severe	—	20 (4)	—	S: Concrete cracked and displaced
	Moderate	—	15 (4)	—	M: Concrete will crack
	Light	—	9 (4)	—	L: Concrete slightly cracked
Machinery General Bolted down	Severe	30 (1)	25 (4)	—	S: Gears & functional parts destroyed
	Moderate	10 (1)	15 (4)	—	M: Auxiliary equipment destroyed
	Light	5 (1)	10 (4)	—	L: Destroys alignment

NOTE: Air shock for exposed equipment.
Ground shock applies to equipment exposed or in buildings.

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TABLE VIII, PART I (Cont'd)

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
R.R. Cars (Box, Tank, & Gondolas)	Severe	10 (2)	25 (4)	10 (4)	S: Pushed over and twisted, probable fires
	Moderate	6 (2)	15 (4)	6 (4)	M: Disalignment
	Light	4 (4)	——	4 (4)	L: Scorching, sides st[illegible]d

NOTE: For average orientation. Also above figures for empty cars, if loaded, multiply psi by 2.

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
R.R. Locomotives	Severe	20 (4)	25 (4)	——	S: Pushed over and twisted
	Moderate	——	15 (4)	——	M: Disalignment
	Light	——	——	——	
Small Arms	Severe	36 (1)	——	——	S: Stock broken, barrel bent
	Moderate	5 (1)	——	——	M: If stacked, will be thrown about
	Light	3 (1)	——	10 (1)	L: Few thrown about and scorched
Tanks (Heavy & Medium)	Severe	60 (4)	——	——	S: Tanks overturned and tracks and hatches knocked off
	Moderate	35 (1)	——	——	M: Tanks overturned; hatches, guns and tracks damaged
	Light	——	——	——	

NOTE: Personnel - see Part V

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
Vehicles, Heavy & Light Tanks	Severe	30 (4)	——	——	S: Vehicles overturned and destroyed
	Moderate	15 (4)	——	——	M: Vehicles overturned
	Light	3 (1)	——	15 (4)	L: Glass Broken, Seats burned

NOTE: Thermal effects depend on amount of inflammable materiel present

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^2	REMARKS
Vehicles (light)	Severe	20 (4)	——	——	S: Vehicles overturned and destroyed
	Moderate	10 (1)	——	——	M: Vehicles overturned
	Light	3 (1)	——	15 (4)	L: Glass broken, seat burned

NOTE: Thermal effects depend on amount of inflammable materiel present.

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TABLE VIII
PART II
STRUCTURES

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm²	REMARKS
Brick Walls (12-18 inch)	Severe	12 (1)	15 (4)	—	S: Collapse
	Moderate	8 (1)	10 (4)	—	M: Partial collapse & cracking
	Light	3 (1)	6 (4)	—	L: Cracking
Homes Brick	Severe	6 (1)	15 (4)	—	S: Collapse
	Moderate	4 (1)	10 (4)	—	M: Distortion and Cracks
	Light	3 (1)	6(4)	—	L: Plaster & window damage
Homes Wooden Frame	Severe	5 (1)	25 (4)	20 (1)	S: Collapse, Burns
	Moderate	3 (1)	15 (4)	12 (1)	M: Distortion & cracks, may burn
	Light	2 (1)	8 (4)	8 (1)	L: Plaster & window damage, scorched
Multistory Brick Bldg.	Severe	6 (1)	15 (4)	—	S: Collapse
	Moderate	4 (1)	10 (4)	—	M: Structural Damage
	Light	3 (1)	6 (4)	—	L: Plaster & window damage
Oil Tank Farms	Severe	10 (2-4)	—	—	S: Tank collapse. This based on Texas explosion. Fires may break out & destroy entire field.
	Moderate	—	—	—	
	Light	—	—	—	
Reinforced Concrete Bldgs.	Severe	25 (1)	30 (4)	—	S: Collapse
	Moderate	10 (1)	20 (4)	—	M: Structural damage
	Light	3 (1)	15 (4)	—	L: Plaster & window damage
Steel, heavy frame Bldgs.	Severe	18 (1)	20 (4)	—	S: Mass distortion
	Moderate	12 (1)	10 (4)	—	M: Structural Damage
	Light	3 (1)	8 (4)	—	L: Plaster & window damage
Steel, light frame Bldgs.	Severe	10 (1)	15 (4)	—	S: Mass distortion
	Moderate	5 (1)	10 (4)	—	M: Structural Damage
	Light	3 (1)	6 (4)	—	L: Plaster & window damage

TABLE VIII
PART II (Cont'd)

NOTE: If acceleration or displacement is used as Ground Shock Criteria, moderate damage is to be expected to wall bearing brick buildings, chimneys, brick structures and underground utilities if the acceleration is greater than 1 g or the displacement is greater than 0.03 inches. (See Figures 3.52a and 3.55). However, the use of displacement as criteria is not recommended.

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TABLE VIII
PART III

SEA OPERATIONS

ITEM	DAMAGE	AIR SHOCK PSI	WATER SHOCK *Energy Flux, see Fig. 6.74	WATER SHOCK Bikini "B" Distance (ft)	REMARKS
Aircraft Carriers	Severe	30 (1)	300(4)	2700(1)	S: Complete destruction or sunk
	Moderate	20 (1)	200(4)	3000(1)	M: Immobilized. Failure of primary departments such as elevators. Air shock distorts flight deck.
	Light	5 (1)	100(4)	4500(1)	L: Scorching & damage to light and electronic equipment.
Battleships	Severe	45 (1)	300(4)	2700(1)	S: Complete destruction or sunk
	Moderate	25 (1)	200(4)	3000(1)	M: Immobilized. Failure of primary departments
	Light	5 (1)	100(4)	4500(1)	L: Scorching & damage to light and electronic equipment.
Cruiser (Heavy)	Severe	40 (1)	300(4)	2700(1)	S: Complete destruction or sunk
	Moderate	20 (1)	200(4)	3000(1)	M: Immobilized. Failure of primary departments
	Light	5 (1)	100(4)	4500(1)	L: Scorching & damage to light and electronic equipment.
Cruiser (light)	Severe	30 (1)	300(4)	2700(1)	S: Complete destruction or sunk
	Moderate	20 (1)	200(4)	3000(1)	M: Immobilized. Failure of primary departments.
	Light	5 (1)	100(4)	4500(1)	L: Scorching & damage to light and electronic equipment.
Destroyers	Severe	25 (1)	300(4)	2700(1)	S: Complete destruction or sunk
	Moderate	15 (1)	200(4)	3000(1)	M: Immobilized. Failure of primary departments.
	Light	5 (1)	100(4)	4500(1)	L: Scorching & damage to light and electronic equipment.

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TABLE VIII

PART III - WATER SHOCK - Continued

ITEM	DAMAGE	AIR SHOCK PSI	ENERGY FLUX Fig. 6.74	BIKINI "B" Distance(ft)	REMARKS
Pontoons (For Pier Construction)	Severe	60 (1)	—	2000(4)	S: Collapse or sunk
	Moderate	—	—	—	
	Light	—	—	—	
Transports	Severe	30 (1)	300 (4)	2700 (1)	S: Complete destruction or/sunk
	Moderate	20 (4)	200 (4)	3000 (1)	M: Immobilized
	Light	5 (4)	100 (4)	4500 (1)	L: Superstructure & external equipment slightly damaged
Submarine (Surfaced)	Severe	80 (1)	300 (4)	2700 (1)	S: Collapse of shell or sunk
	Moderate	60 (1)	200 (4)	3000 (1)	M: Immobilized
	Light	—	—	—	

Submarines (Submerged)

1. The damage criteria for this important target are relatively little understood. Therefore, damage is presented below as lethal radius as a function of horizontal distance for various depths of the submarine and depths of bomb explosion. These data are based largely on actual data from full-scale weapon tests for a 20 KT yield only. For data based on scaled experiments and full-scale (20 KT) tests, see Figure 10.

KT	BOMB DEPTH (FT)	SUB DEPTH (FT)	LETHAL RADIUS(HORIZONTAL)(MILES)
20	90	70	0.5
20	90	500	1
20	500	70	1
20	500	500	2
20	2000	70	2
20	2000	500	4

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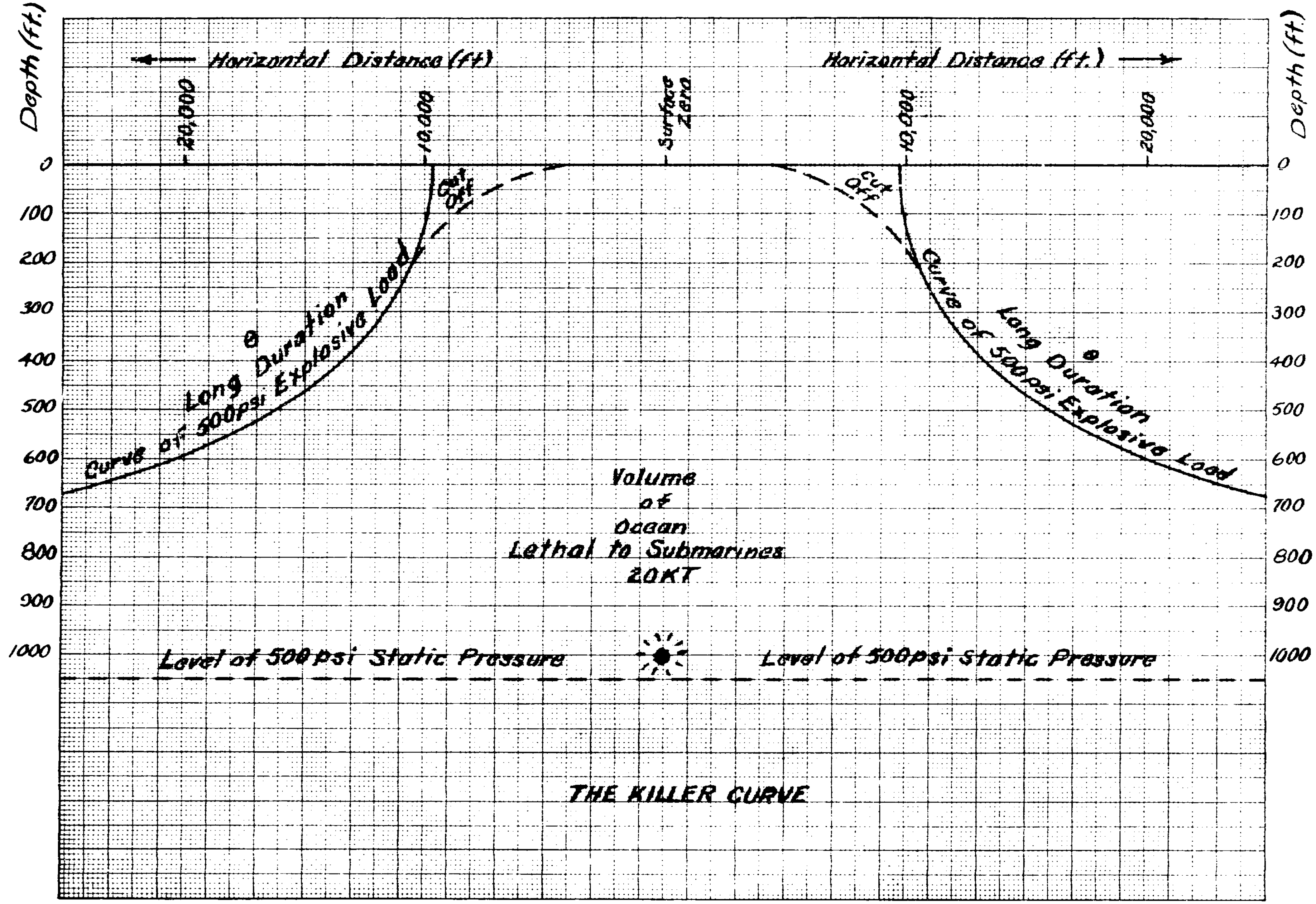
Depth (ft.)
Horizontal Distance (ft)
Horizontal Distance (ft.)
20,000
10,000
Surface Zero
10,000
20,000
Depth (ft.)
0
100
200
300
400
500
600
700
800
900
1000
Cut Off
Cut Off
Curve of 500psi Explosive Load @ Long Duration
Curve of 500psi Explosive Load @ Long Duration
Volume of Ocean Lethal to Submarines 20KT
Level of 500psi Static Pressure
Level of 500psi Static Pressure
THE KILLER CURVE

Figure 10

TABLE VIII
PART III - WATER SHOCK - Continued

* Energy Flux to be used with Graph 6.74 and pertains to atomic explosions at optimum depth in deep water. Near the surface, the energy flux varies directly as the depth of target. Since ships with heavy hulls will have greater draughts than light hull ships, it can be stated that as a general rule ships at the same distance from the explosion will suffer essentially the same hull damage.

NOTES:

1. Ordnance Equipment on Ships: Due to bolting down of armament, it is more resistant to blast. Multiply artillery psi criteria in Part I by a factor of 1.5. S: Damage to traversing and elevating mechanisms. M: Electronic transmission systems and directors destroyed. L: Scorching and destruction of sights in 40mm AA guns.

2. In all cases 15 (4) cal/cm^2 will scorch ship and exposed equipment.

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TABLE VIII
PART IV – AIR OPERATIONS

ITEM	DAMAGE	AIR SHOCK PSI	GROUND SHOCK ER	THERMAL ENERGY cal/cm^{-2}	REMARKS
Aircraft (Parked)	Severe	6 (1)	---	70(4)	
	Moderate	3 (1)	---	30(4)	
	Light	1.5(1)	---	15(4)	S: Complete destruction or burned
					M: Wing and fuselage damage
					L: Fabric damage
Aircraft (Airborne)	Severe	5 (4)	---	70(4)	
	Moderate	3 (4)	---	30(4)	
	Light	2 (4)	---	15(4)	
Barrage Balloons	Severe	---	---	15(4)	S: Balloon burns
	Moderate	---	---	---	
	Light	---	---	---	

TABLE VIII
PART V - PERSONNEL

Situation	Damage	Thermal Energy cal/cm^2	Nuclear Radiation Short-Time Dose r	Air Shock psi	Remarks
Personnel in open	S	20 (1)	400 (1)	12 (4)	Casualties defined in Section 2. Temperate zone uniform. Air shock damage due to secondary blast effects.
	M	10 (1)	250 (1)	8 (4)	
	L	4 (1)	150 (1)	4 (4)	
Personnel in foxholes	S	200 (4)	4000 (1)	—	
	M	100 (4)	2500 (1)	—	
	L	40 (4)	1500 (1)	—	
Personnel in forests	S	20 (4)	400 (4)	7 (4)	Conflagration will occur in dry forests. A wet forest offers protection from thermal. Values here for moderately dry, open forest. Secondary blast damage by falling trees or limbs.
	M	10 (4)	250 (4)	5 (4)	
	L	4 (4)	150 (4)	3 (4)	
Personnel in city	S	20 (1)	1000 (1)	8 (1)	Nuclear assumes an average equivalent protection of 6" concrete. Secondary fires and blast effects primary cause of casualties.
	M	12 (1)	650 (1)	6 (1)	
	L	5 (1)	350 (1)	[illegible] (1)	
Personnel in tanks	S	—	600 (4)	35 (4)	Nuclear damage based on [illegible]" steel in top of tank. Tank accelerations from air shock cause of personnel injury.
	M	—	400 (4)	20 (4)	
	L	—	200 (40	10 (4)	

PART V (Cont'd)

PERSONNEL

SITUATION	DAMAGE	THERMAL ENERGY cal/cm^2	NUCLEAR RADIATION SHORT-TIME DOSE r		AIR SHOCK PSI	REMARKS
			AirBurst	Underwater		
Personnel in Ships (Battleships)	S	—	8000(1)	20,000(1)	—	A wide variation in dosage will be obtained in different parts of ships due to different shielding available. Possibility of personnel injury due to ship accelerations from underwater shock.
	M	—	1000(1)	1,400(1)	—	
	L	—	400(1)	600(1)	—	
Cruisers and Carriers	S	—	1500(1)	3,000(1)	—	
	M	—	800(1)	1,200(1)	—	
	L	—	350(1)	500(1)	—	
Destroyers and Transports	S	—	800(1)	2,000(1)	—	
	M	—	500(1)	800(1)	—	
	L	—	300(1)	400(1)	—	

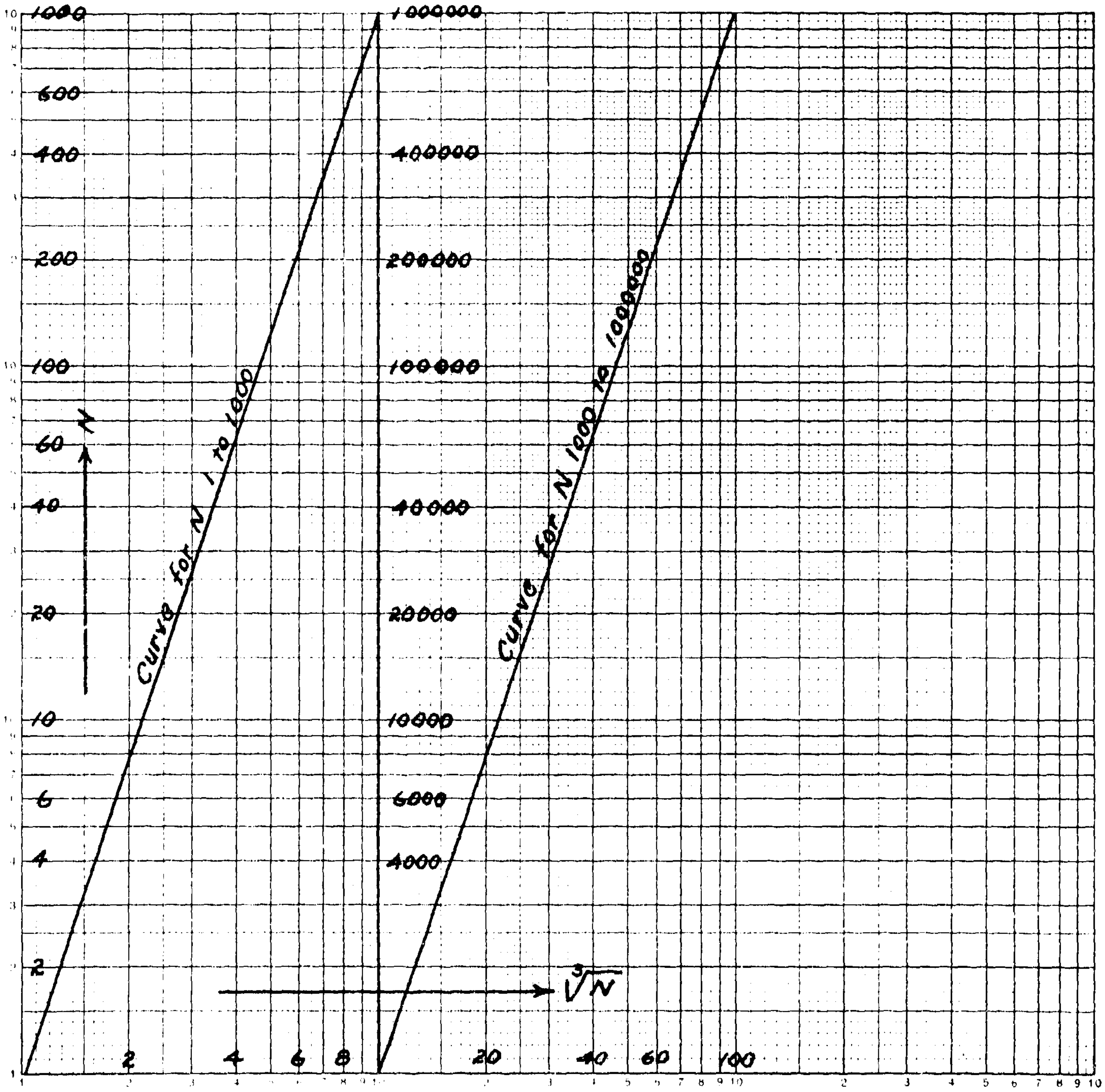

Figure Cube Root of Numbers (N)

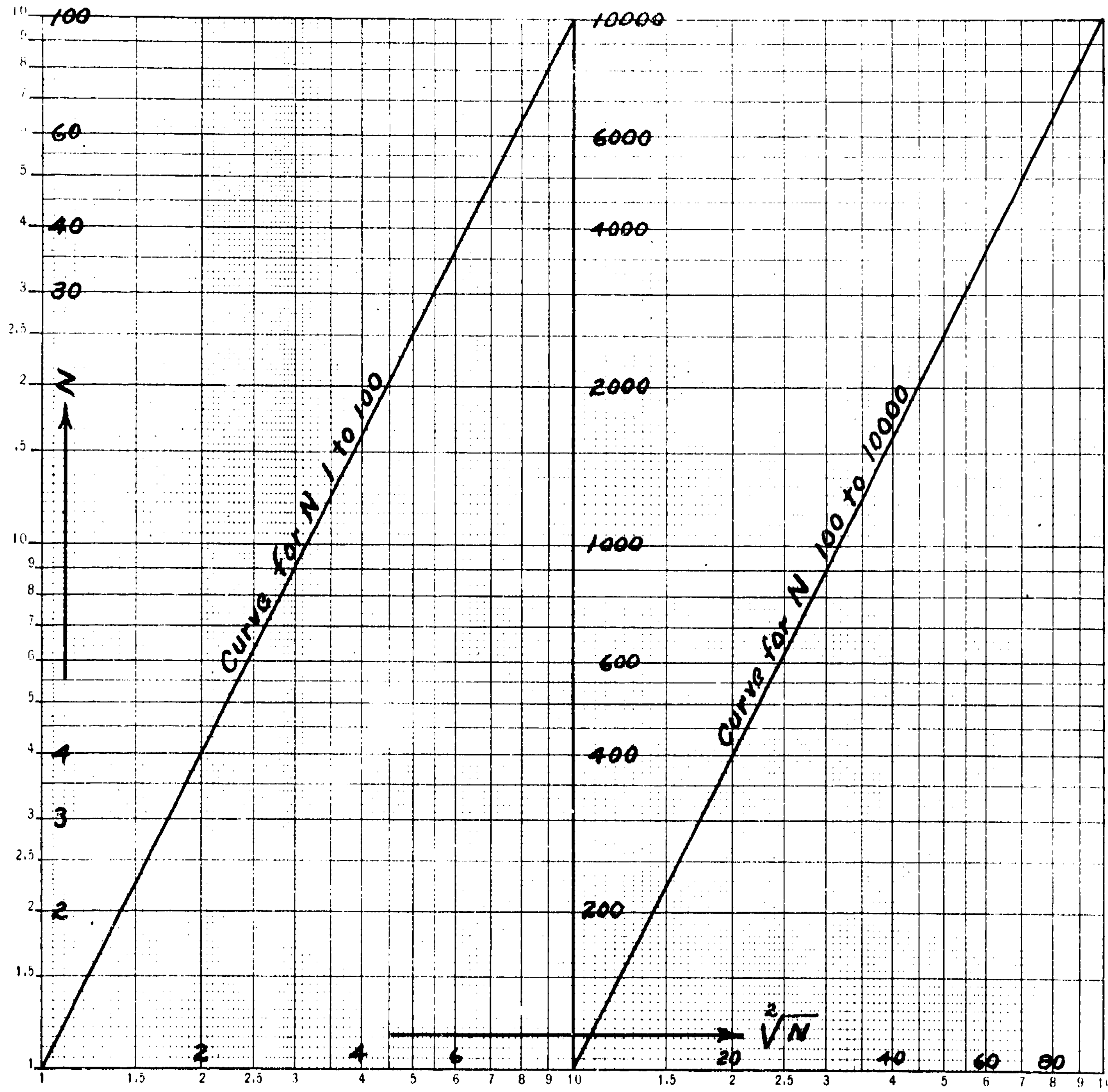

Figure Square Root of Numbers (N)

Defense Special Weapons Agency
6801 Telegraph Road
Alexandria, Virginia 22310-3398

TRC 15 June 1998

MEMORANDUM TO DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OCQ/Mr. William Bush

SUBJECT: Declassification of AD511880L

The Defense Special Weapons Agency Security Office (OPSSI) has reviewed and declassified the following document:

Handbook of Capabilities of Atomic Weapons
Preliminary Copy for The Capabilities and Effects Course
at Sandia Base, New Mexico
The Armed Forces Special Weapons Project
Washington, D. C.
AD-511880L.

Distribution statement **"A" (approved for public release)** now applies.

Because this is a FOIA action, DSWA requests this action be expedited through the National Technical Information Service.

Naomi J. Fields
for ARDITH JARRETT
Chief, Technical Resource Center